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U. S. ARMY
TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

TCREC TECHNICAL REPORT 62-33

HELICOPTER STATIC ELECTRICITY DISCHARGING DEVICE

Task 1D121401A14130
(Formerly Task 9R38-01-017-30)
Contract DA 44-177-TC-728

December 1962

prepared by:

KELLETT AIRCRAFT CORPORATION
Willow Grove, Pennsylvania

HEADQUARTERS
U S ARMY TRANSPORTATION RESEARCH COMMAND
Fort Eustis, Virginia

The work described in this report was accomplished by the Kellett Aircraft Corporation for the U. S. Army Transportation Research Command. The report documents the design, fabrication, and testing of an automatic system for the dissipation of static electricity from helicopters.

The conclusions made in the report are justified and are concurred in by this command. The work described in recommendation 1 is not considered feasible for implementation at this time. The work described in recommendations 2 and 3 has been accomplished and will be reported in subsequent publications.

Additional efforts are being expended by this command in the research of static charge generation and dissipation. Investigations are being made into other dissipation methods, the charging rates, etc., which were experienced in various atmospheres, and the effects of operating variables on the generation properties of helicopter blades. Reports on these projects will be distributed as they become available.

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PREFACE

This report was prepared by the Kellett Aircraft Corporation under the United States Army Contract Number DA 44-177-TC-728. The program was originated by the U. S. Army Transportation Research Command at Fort Eustis, Va. Mr. Blair Poteate was the Army Project Engineer and Mr. Juan de la Cierva was the Kellett Aircraft Corporation Project Engineer.

The project was conducted through the period of March to December 1961.

The assistance of Mr. Blair Poteate and Edwards AFB flight test personnel and the U. S. Army Aviation Test Office at Edwards Air Force Base are acknowledged.

CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

I. SUMMARY

This report presents the results of a program for the alleviation of static electricity problems associated with helicopters. During the program a static electricity discharging device for helicopters was designed, built and tested. Flight tests were performed with an H-37 helicopter under a number of different flight conditions. During these flights conducted in a natural charging current of 2 microamperes, the discharging device maintained the electrostatic energy level at below 1 millijoule. It has been established that this energy level satisfactorily alleviates the existing problems caused by the presence of electrostatic charge. Factors affecting the performance of the device are listed, and recommendations are made to optimize future discharger research. Also, a test program was conducted to determine the performance of high voltage corona point probes under varying conditions of vehicle charge and polarity, corona point potential and corona point geometry. The capacitance to ground of H-21 and H-37 aircraft was determined experimentally, as well as the effect of the air velocity on the current output of high voltage corona points.

II. CONCLUSIONS

An electrostatic discharging device was designed, built and installed on an H-37 Army aircraft. With the unit in operation, the electrostatic energy level on the aircraft was measured below one (1) millijoule. The energy level in the helicopter without the discharger was over 1000 millijoules. The unit was installed on the rotor hub of the aircraft, and the active corona point dischargers were installed on the trailing edge of two rotor blades at the 20-foot radius station. The discharger was battery operated. The operation and performance of the discharger was considered to be satisfactory.

In addition, the following conclusions were reached:

1. The performance (discharge current vs. applied potential) of the corona points was found to be a nearly linear function of the air speed about the corona point.

2. The ability of the discharging device to sense the presence of electrostatic charge in the helicopter was found to be a direct function of the level of the discharge current of the two corona points with the helicopter at zero voltage, as well as an inverse function of the aircraft generated electrostatic field in the neighborhood of the corona points.

3. The discharger designed and fabricated during the present contract was an engineering breadboard model, built to test the basic principles of the device. Its weight was 28.38 pounds. This weight includes the following items:

a. discharger generators
b. discharger amplifiers
c. discharger batteries
d. probes
e. miscellaneous hardware

A substantial reduction in weight could be achieved through further development of the same basic design.

4. The discharger designed and built under this contract represents a relatively simple and inexpensive system for alleviating the problems created by the electro-

static charge in helicopters for natural charging currents in the neighborhood of 2 microamperes. The discharger, being inherently automatic, will require little maintenance and/or adjustment. The power requirements will be below 20 watts for a large size helicopter.

5. Flight tests indicated that the installation of the device on the rotating parts of the helicopter did not cause any noticeable effect on the flying qualities of the machine.

III. RECOMMENDATIONS

An evaluation of the data obtained during this program results in the following recommendations:

1. A new engineering model of the Dynamic Neutralizer should be designed, built and installed in an aircraft for evaluation by the Army. The device should be built with the same basic performance as the breadboard model used in this program and should be hub-installed. The unit should incorporate the following changes:

   a.) A single-transformer unit should be used, with a basic schematic diagram as shown in Figure 1.

   b.) The power supply should be the 28 V.D.C. supply of the aircraft, fed to the hub-installed unit through a simplified electric rotary coupling, as schematically described in Figure 1.

2. A discharging unit using the same basic principle as 1. above should be tested in a fuselage installation. The reduction in performance of the corona points caused by the slower air speed about fuselage mounted points may be compensated by using a better corona point geometry and a considerably higher generator output voltage. Both improvements could be accomplished in a fuselage-borne installation, and it is considered that the obvious advantage of this configuration makes it worthwhile to conduct the recommended testing.

3. An investigation should be conducted to determine the range of natural charging conditions which may be encountered by operational helicopters.

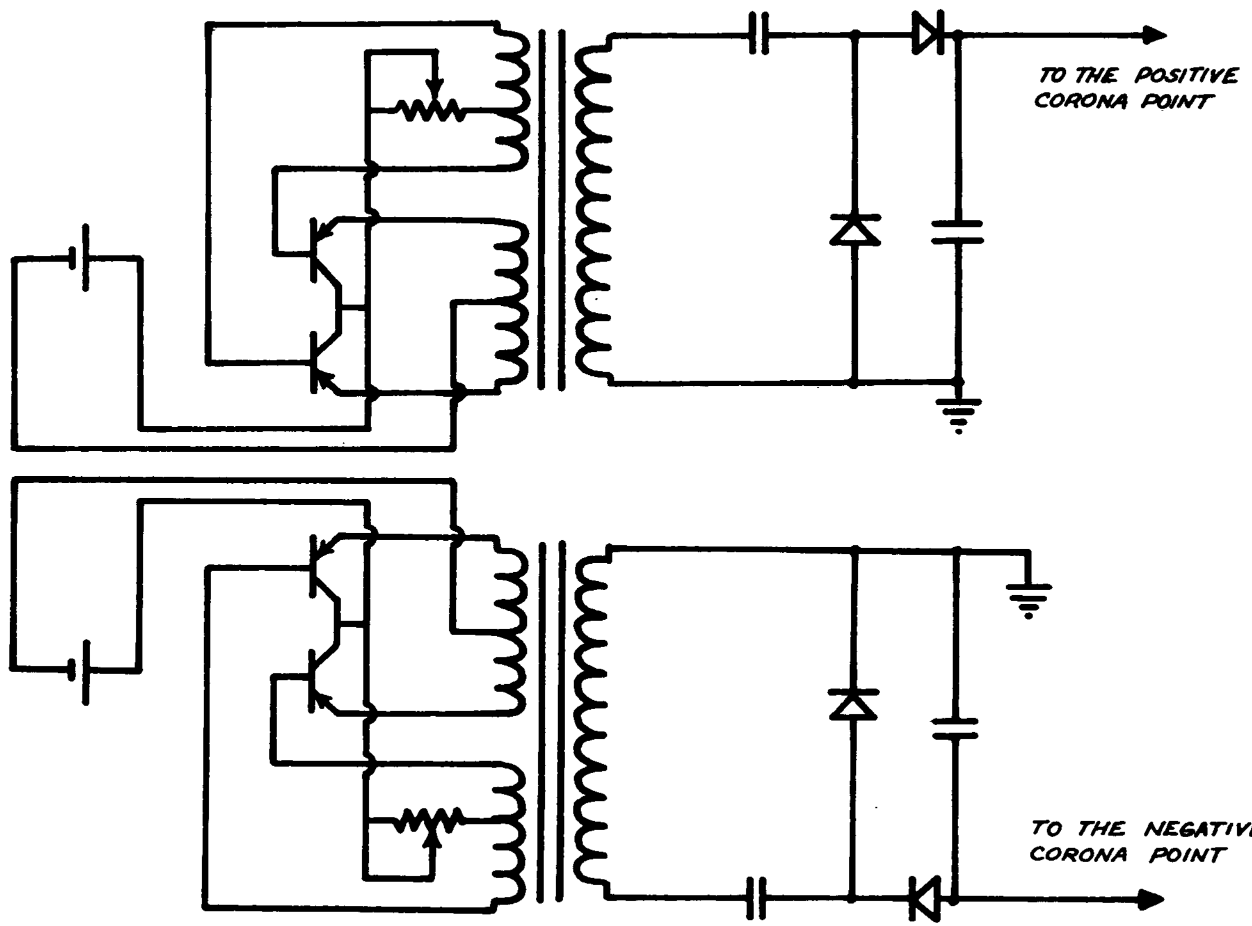


FIGURE 1: DYNAMIC NEUTRALIZER (TESTED UNIT) SCHEMATIC DIAGRAM

IV. DISCUSSION OF THE PROBLEM

A. INTRODUCTION

Any aircraft flying in the atmosphere can be considered as a conductive body located in a highly electrically insulated environment. In such a body, electrostatic charge is generated by three principal mechanisms:

1. Charge transfer created by a triboelectric effect between the aircraft and the atmospheric particles, such as dust, water, water vapor, snow, etc.

2. Unbalance of the ionic content of the exhaust gases produced by the aircraft engine(s).

3. Induction charge due to high electrostatic field gradients which are found occasionally in the aircraft flight path.

The accumulation of electrostatic charge in an aircraft is equivalent to the storing of potential energy. This potential energy may be released if a conductive circuit is established between the aircraft and ground.

In a fixed-wing airplane, the presence of a physical short-circuiting element to ground is very unlikely. The principal effect of the charge accumulation in a fixed-wing aircraft is related to the radio interference produced by the release of energy through natural corona points on the aircraft. This problem was analyzed in Reference 1, and is substantially eliminated by the use of passive electrostatic dischargers, as described in Reference 2.

In helicopters, there are three principal problems caused by the accumulation of electrostatic charge:

1. The electrostatic shock received by ground personnel handling external cargo suspended from a hovering helicopter.

2. The electrostatic spark-ignition of air-fuel mixtures produced by a rescue sling dropped from a helicopter hovering over a crash area.

3. The self-ignition of starters and detonators on externally carried weapon systems.

Consequently this program was initiated to design, build and test an automatic electrostatic discharger able to maintain a large Army helicopter, such as the H-37, at an electrostatic energy level sufficiently low to eliminate the dangerous effects listed above. In accordance with References 3 to 6, a satisfactory minimum energy level was determined to be equal to one (1) millijoule.

The program consisted of two phases:

Phase I. Parametric Tests

Phase II. Flight Tests

During the parametric test phase, data were accumulated for the purpose of establishing the design parameters of the discharging system. Following this, the system was designed, built and flight tested on an H-37 helicopter.

B. ANALYSIS OF THE PROBLEM

The electrostatic energy which a flying helicopter will release to ground through a suitable discharging circuit may be calculated from:

$$W = 1/2\ CV^2 \qquad (1)$$

where W = Electrostatic energy, joules

C = Aircraft capacitance to ground, farads

V = Difference of potential between the aircraft and ground, volts

Clearly, the determination of the capacitance of the aircraft is needed in order to refer the energy level to a relatively easily measurable parameter such as the aircraft voltage.

Hence, the capacitance of an H-37 aircraft was measured as a function of the altitude. Measurements were also conducted with an H-21 helicopter. Figure 2 gives the result of these measurements and Figure 3 describes the technique used to obtain the data.

In Figure 4, the voltage of an H-37 helicopter is plotted against helicopter altitude for constant electrostatic energy levels. Figure 4 was obtained using the data on Figure 2 and Equation (1). In the ensuing discussion, an H-37

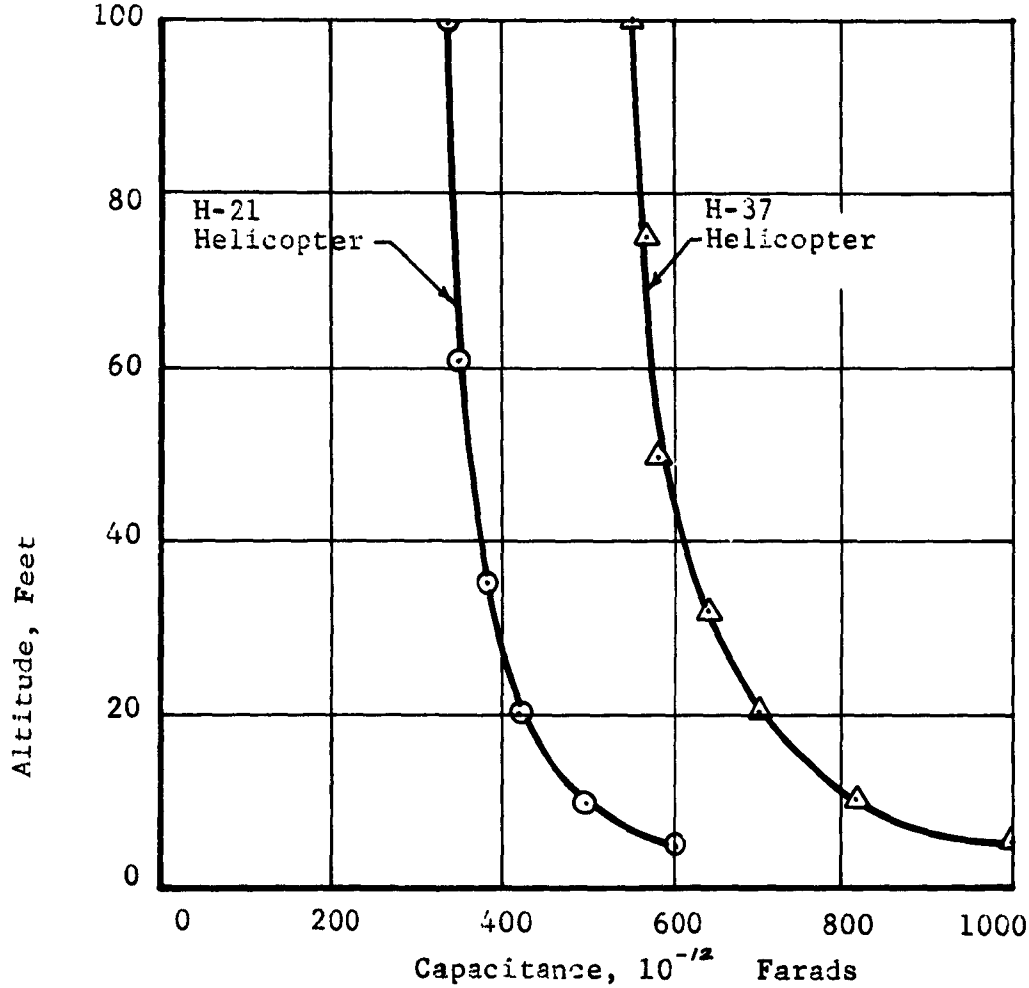
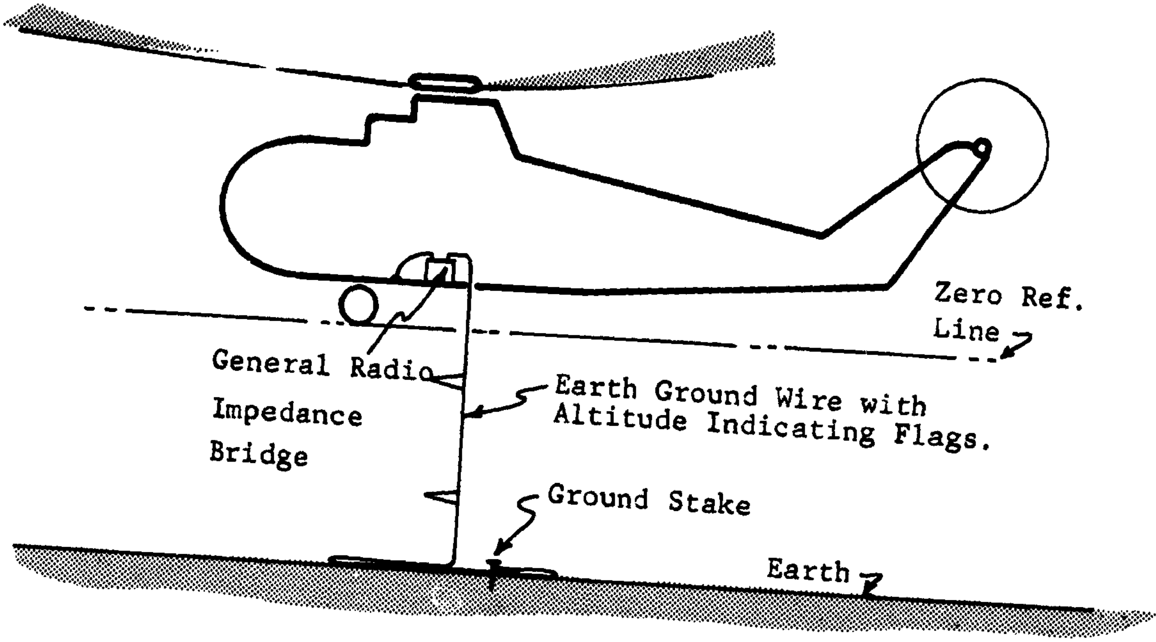


FIGURE 2: H-37 AND H-21 HELICOPTER CAPACITANCE TO GROUND CHART



TEST PROCEDURE:

1. Hover the aircraft at a specific altitude, H_n
2. Read the bridge indication, C_n
3. Repeat 1 and 2 at all altitude points within the range.
4. Fly the helicopter at 1000 feet with the cable hanging down. Measure the capacitance C_c between the aircraft and the test cable.
5. Calculate the Capacitance C_{Hn} at an altitude H_n by

$$C_{Hn} = C_n - C_c$$

FIGURE 3: CAPACITANCE MEASUREMENT TECHNIQUE

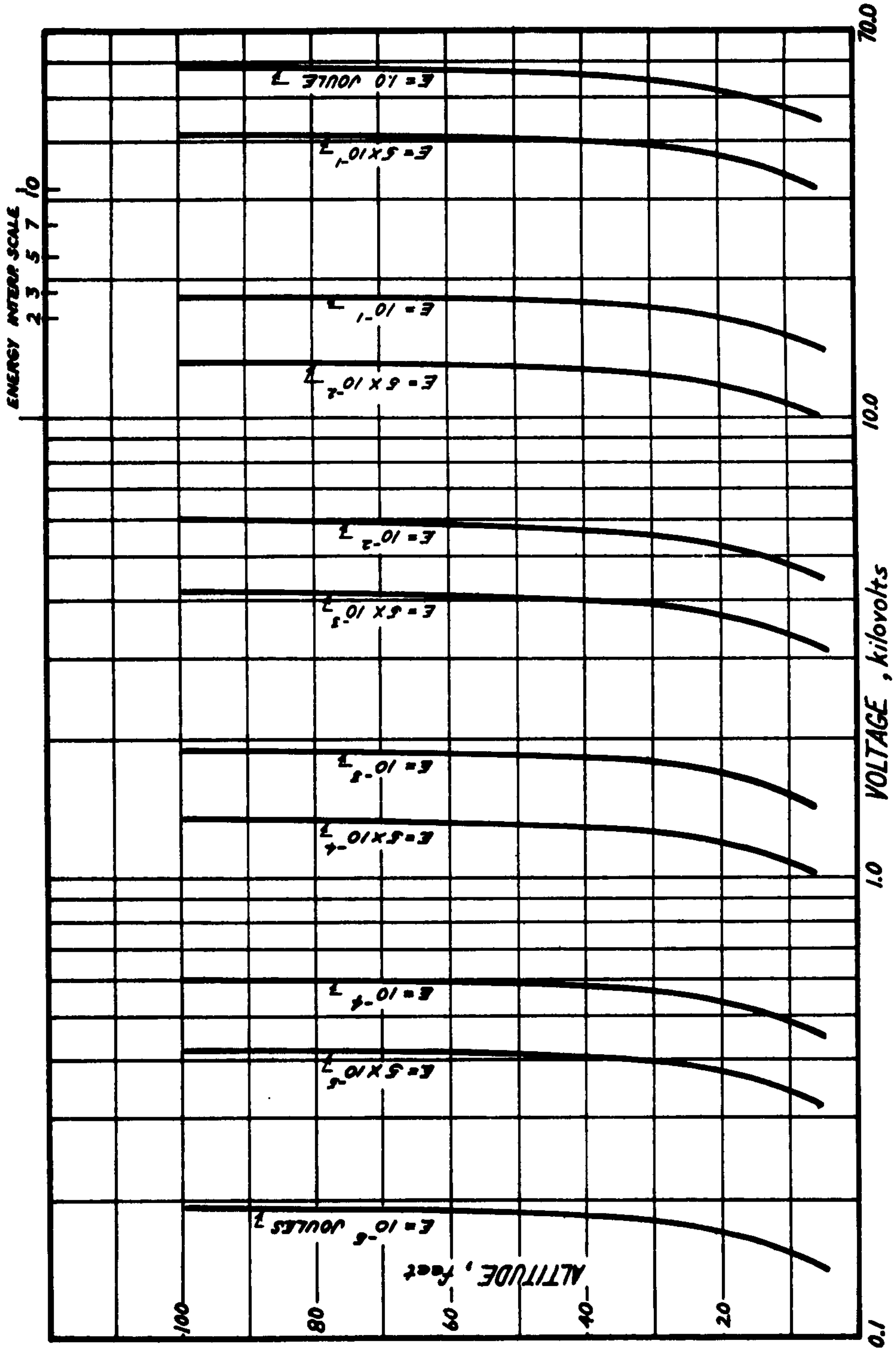


FIGURE 4: H-37 ELECTROSTATIC ENERGY

helicopter with an energy level that is located on the left side of the 10^{-3} joule curve will be considered discharged.

C. ELECTROSTATIC DISCHARGER DESCRIPTION

The design of the discharger device was such that by some on-the-spot modifications it was possible to test the operation of two completely different principles of electrostatic discharging. The first principle was based on the use of the natural discharging current due to the aircraft rise in potential as a sensing magnitude to detect the presence and polarity of electrostatic build-up on the helicopter.

This detection was performed by using a sensing device consisting of a passive corona point connected to the helicopter through a resistive circuit. Any current flowing through the passive corona point due to a rise in the aircraft voltage creates a potential across the resistor. This potential, therefore, is the input signal to an amplifying system, which controls the polarity of the high-voltage generators.

To avoid the necessity of polarity switching of high-voltage components, the unit incorporates two high-voltage generators (HVG). The control amplifier is connected to the primary stages of these generators, where the voltage is sufficient to permit the use of commercially available components and standard design techniques. The high-voltage generators (HVG) are connected to active corona points which accomplish the actual discharging of the helicopter.

Figure 5 is a block diagram of this unit. This discharging unit is referred herein as PCPSD, for Passive Corona Point Sensing Device.

The second principle utilized only a part of the components used in the PCPSD system. It is referred to as the Dynamic Neutralizer, and has the following operation:

Two high-voltage generators (HVG) are connected with opposite polarity to the aircraft frame on one side and to two corona points on the other side, as described in Figure 5. The voltage output of both generators is made equal, as well as the relative position of both corona points with respect to the aircraft and the air speed on both corona points. Under these circumstances, and assuming a neutral aircraft, the current flow on both corona points will have the same value and the net charge accumulating on the aircraft will be zero.

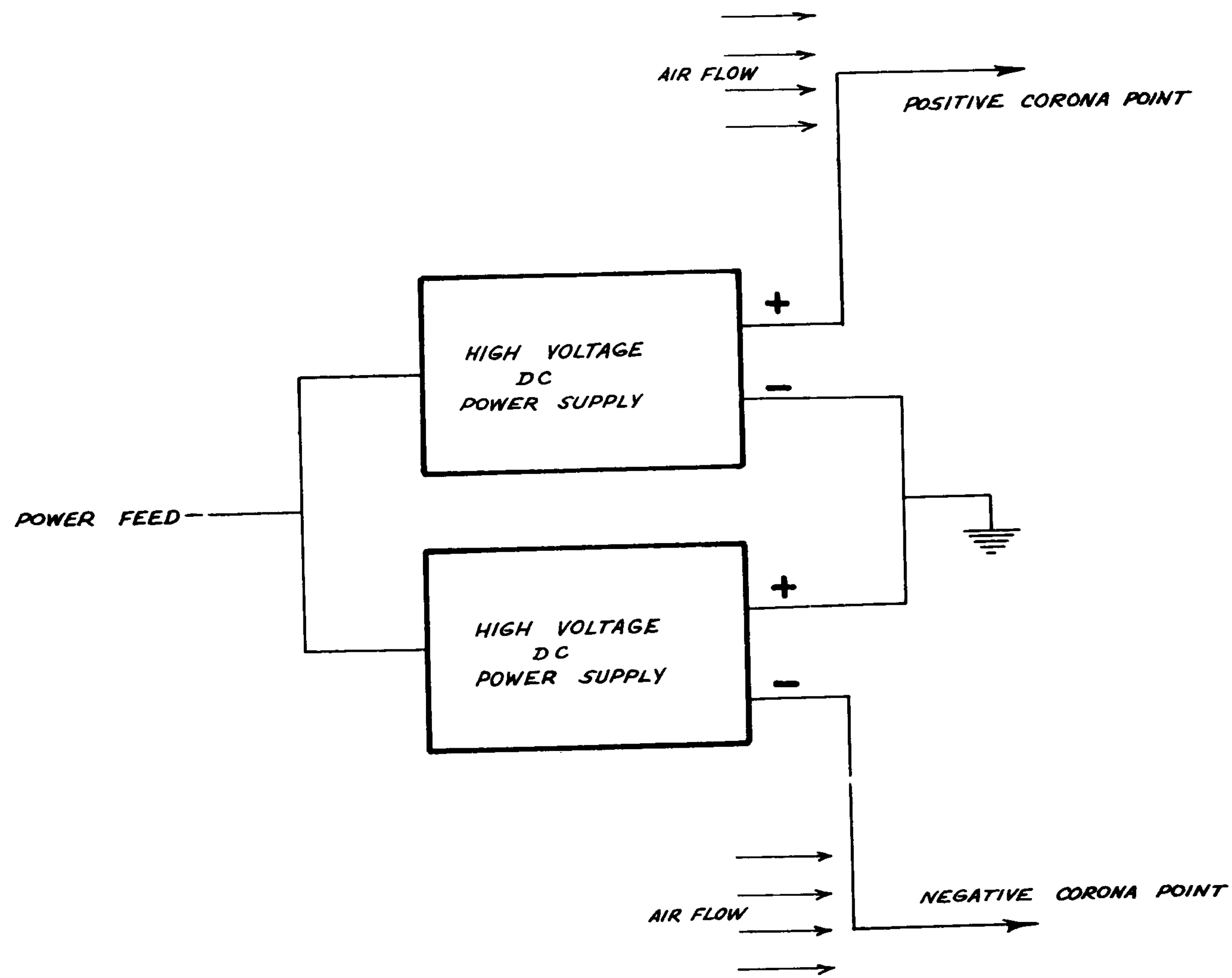


FIGURE 5: DYNAMIC NEUTRALIZER BLOCK DIAGRAM

If, due to a natural charging current, the aircraft becomes charged, its potential with respect to the surrounding air increases. Assuming that the natural charging develops a positive charge in the helicopter (if negative, all polarities should be reversed in this discussion), the total potential between the positive corona point and the surrounding air increases, and the total potential of the negative corona point with respect to the air decreases. Consequently, the output of the positive corona point is boosted and the output of the negative corona point is reduced. Under these new conditions and because of the unbalance of the positive and negative currents, the aircraft takes in a net charge through the discharging system with a polarity that is opposed to that of the natural charge which created the aircraft potential. In the example described above, the output of the positive HVG being higher than that of the negative HVG, the net result is a negative charge input which will compensate for the natural positive charge which caused the rise in electrostatic potential of the aircraft.

Several factors affect the operation and performance of such a discharging system. The most important are:

1. The Corona Point geometry and location with respect to the aircraft geometry.

2. The Corona Point performance (current per unit volt), which, in turn, is affected by two basic factors:

    a. The HVG operating voltage
    b. The air speed at the corona point

Both discharging principles were tested using the same actual unit wired in different ways to perform either type of operation.

Figure 6 is a photograph of the discharger, and Figure 7 is a photograph of the unit as mounted on the rotor hub of the H-37 test aircraft. The volume of this device was .15 cubic feet. As shown in Appendix II, its weight was 10.5 pounds without batteries and 12.8 pounds including batteries and a radio-controlled switch used during the testing. It is pointed out that the unit was designed and built as an engineering breadboard model and, hence, substantial reductions on size and weight are considered feasible in an eventual production item.

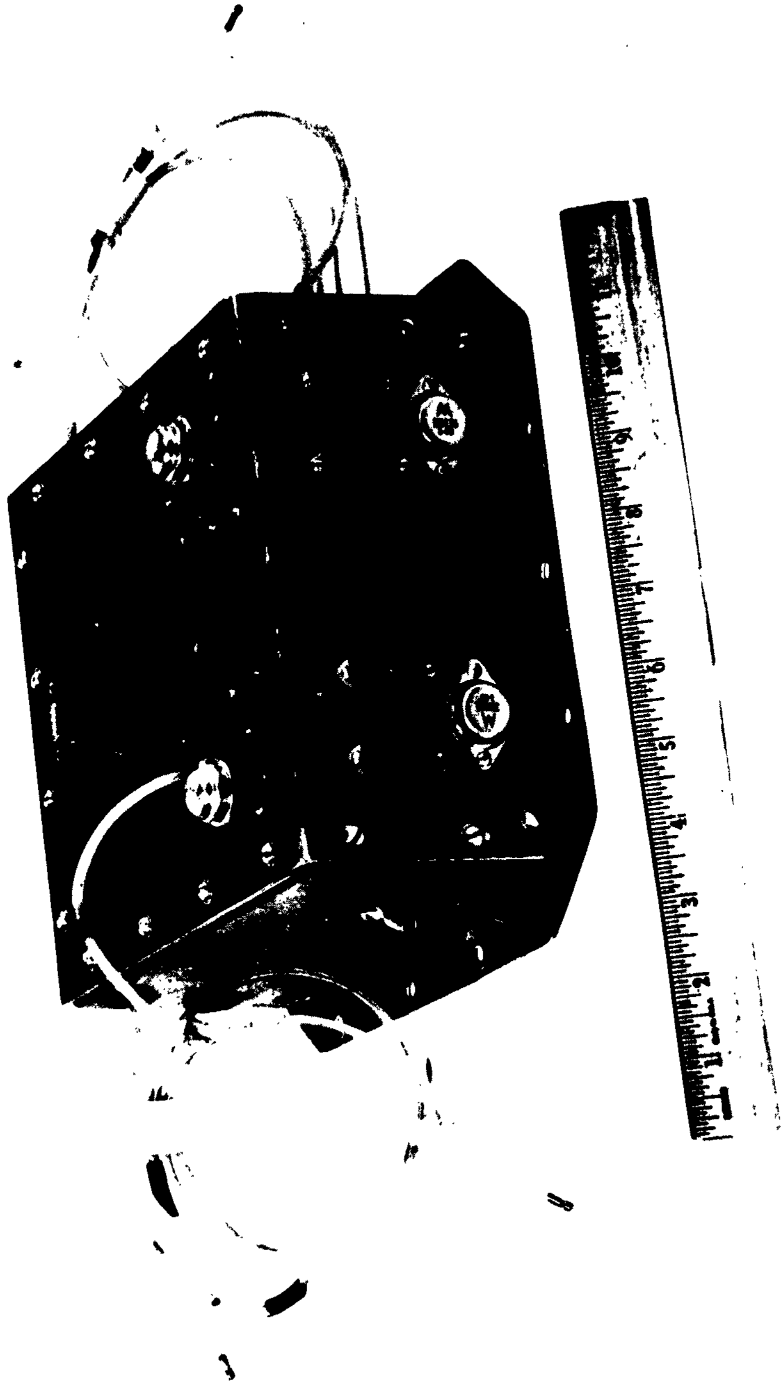


FIGURE 6: DISCHARGING UNIT

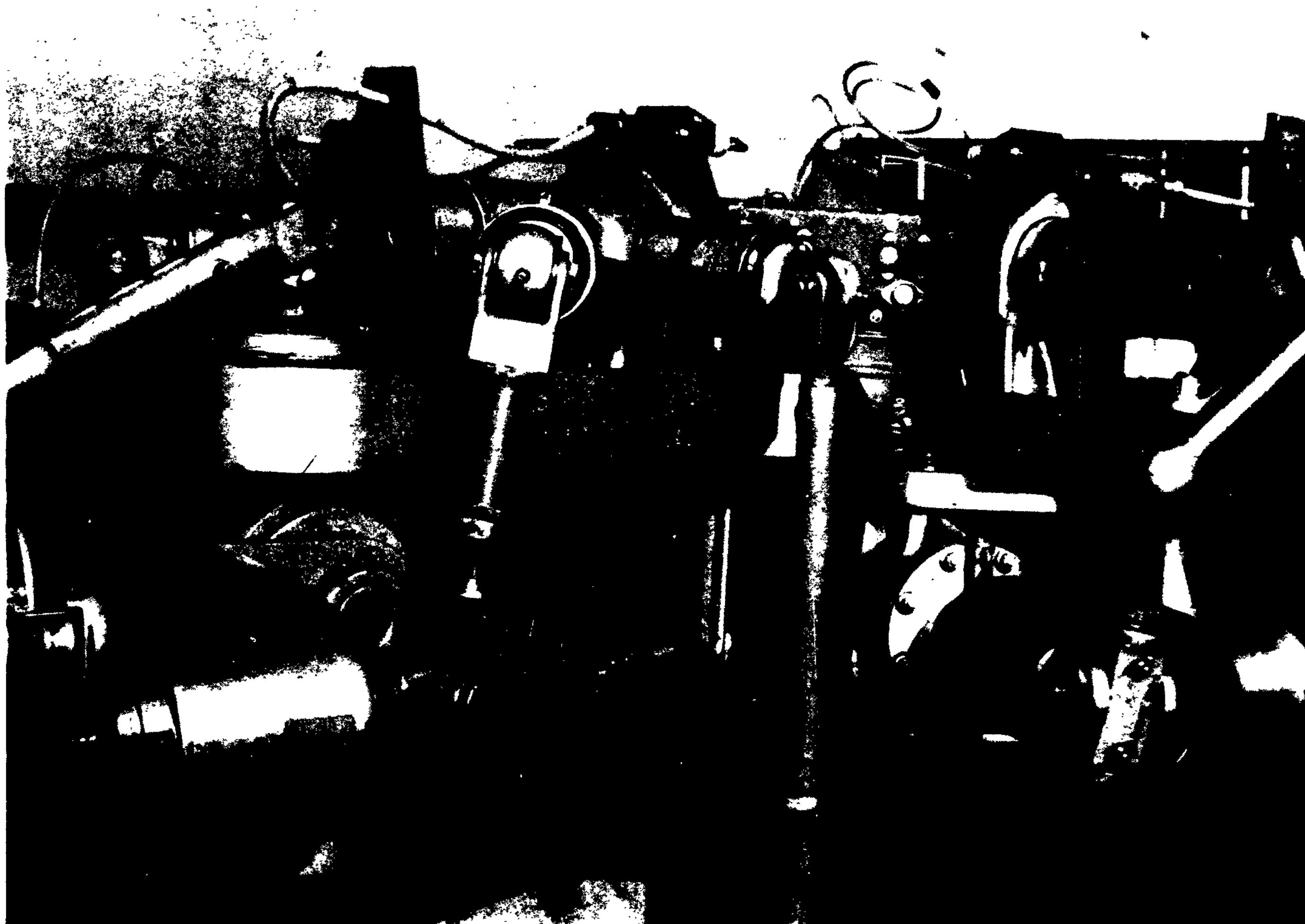


FIGURE 7: DISCHARGING UNIT ON THE H-37 ROTOR HUB

V. EXPERIMENTAL PROCEDURE

A. PARAMETRIC DATA ACQUISITION PHASE

The design of the electrostatic discharger required data in the following areas:

1. Performance of a high-voltage corona point as a function of the aircraft potential and potential gradient.

2. Performance of a high-voltage corona point as a function of the air speed about the point.

3. Effect of the corona point geometry on the performance of a high-voltage probe.

In order to obtain this information, a test rig was prepared using a crane-mounted engine-propeller combination used by the Contractor for another contract, Reference 7. Figure 8 is a photograph of the test rig. Two sets of corona points were installed on the rig. One was located at the tip of the propeller blades, and the other in the propeller downwash region. Air speeds ranging between 0 and 800 feet per second were available with this test rig.

The whole rig was insulated from the ground using sandwiched teflon and plywood supports between the truck tires and the ground.

The insulation to ground of the rig was measured to over 10^{13} ohms.

An electrostatically shielded instrumentation cabin was built on the truck. The following instrumentation was installed in the cabin:

1. A gasoline-powered, 3-horsepower, 24-volt DC generator.
2. A 24-volt DC to 115-volt AC, 60 cycle, 750-watt converter.
3. A DC high-voltage generator with floating $\pm$ 30 kilovolts adjustable output.
4. A DC high-voltage generator, with floating $\pm$ 60 kilovolts adjustable output.
5. Two DC microammeters, ranging between 10^{-8} amperes and 10^{-3} amperes full scale.

FIGURE 8: PARAMETRIC DATA ACQUISITION TEST RIG

6. An electrostatic transistorized voltmeter having an input impedance of 10^{13} ohms, with scale ranges of 10 and 50 kilovolts.

A slip-ring assembly was built and installed on the propeller shaft to connect the instrumentation cabin with the blade tip installed corona points. The slip-ring installation was designed to withstand 30-kilovolt DC voltages.

A commutator panel was designed, built and installed in the cabin commensurate with the high-voltages used in this program. Figure 9 shows the block diagram of the test equipment.

B. <u>FLIGHT TEST PHASE</u>

The measurement of the performance of the discharger on the H-37 was made using the following technique.

A radio-controlled OFF-ON switch was installed on the top of the discharging unit. This radio-controlled switch is shown in Figure 7. A radio transmitter was installed in the helicopter cabin. The measurements were taken in the aircraft cargo compartment. An instrument desk was built, including the following equipment:

1. An electrostatic transistorized voltmeter, ranging 10 kilovolts full scale maximum, having an internal impedance higher than 10^{13} ohms.

2. A 5 to 1 capacitive voltage divider for "1", with the same input impedance.

3. Two DC microammeters, ranging from 10^{-8} to 10^{-3} amperes full scale.

4. A vacuum tube voltmeter.

5. A DC microammeter, 20 microamperes full scale.

6. A 60-kilovolt, reversible polarity, floating output high-voltage generator.

7. A 24-VDC to 115-VAC converter.

Figure 10 is a partial view of the airborne instrument panel; instruments 6 and 7 are not shown. The principal purpose of the test program was to measure the amount of

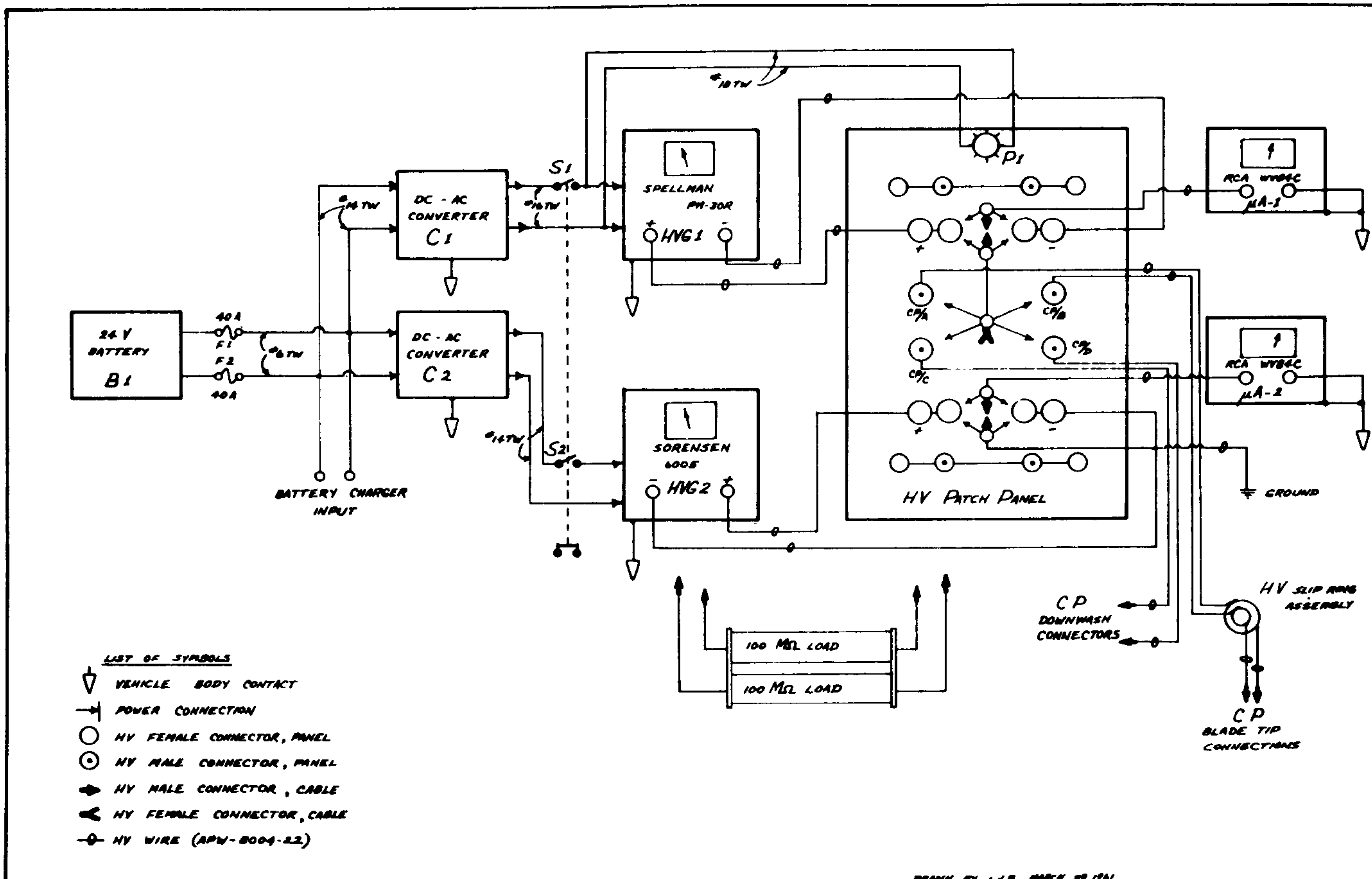


FIGURE 9: PARAMETRIC TESTING RIG, BLOCK DIAGRAM

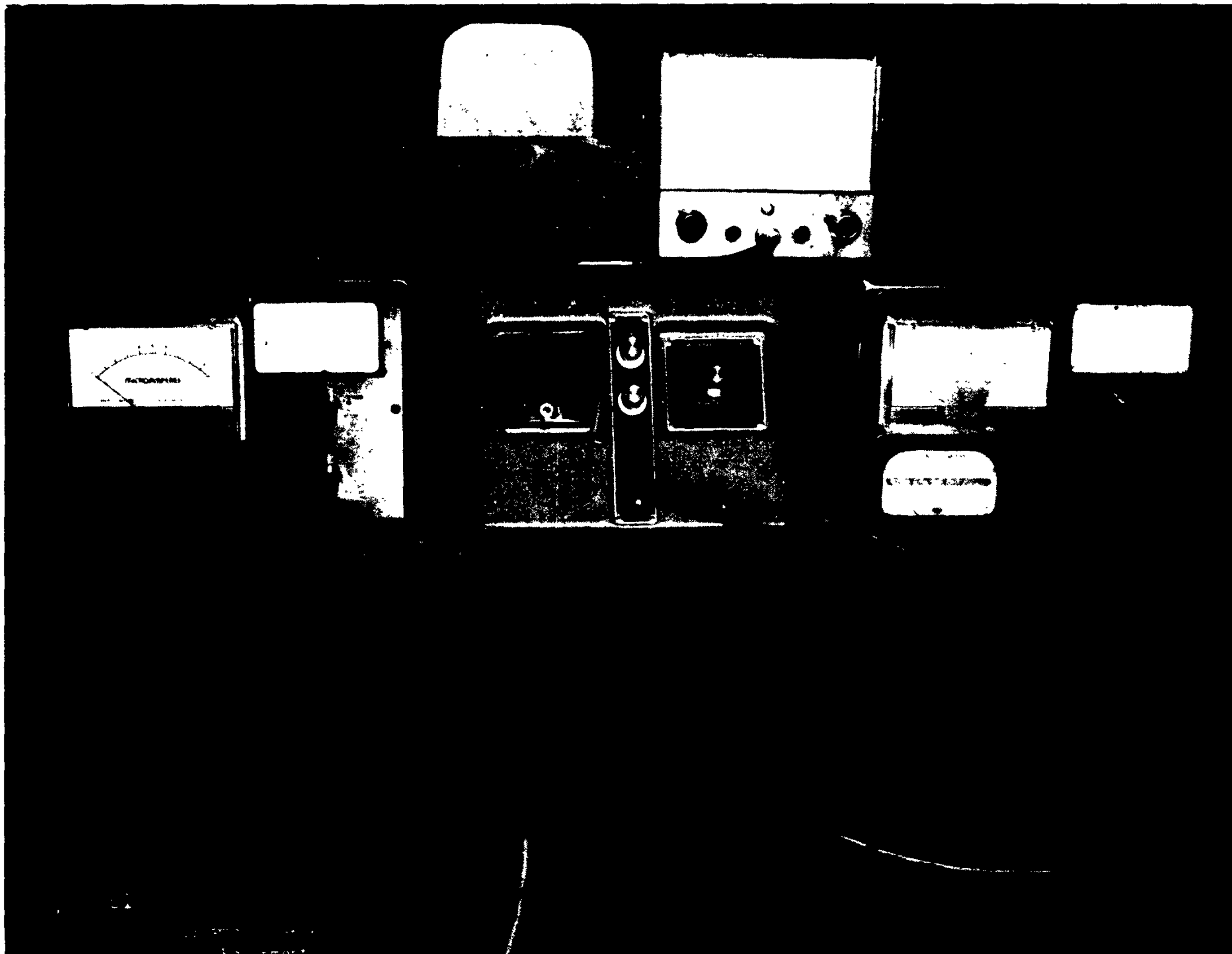


FIGURE 10: H-37 INSTALLED TEST INSTRUMENT PANEL, PARTIAL VIEW

electrostatic energy which the aircraft stores with the system in operation. As a reference level, the electrostatic energy of the H-37 without the discharger was determined.

The parameter actually measured was the aircraft voltage. The measurement was done using a highly insulated wire hanging below the hovering helicopter, and connected to ground. The voltmeter was connected between this wire and the helicopter body. The impedance of the voltmeter (10^{13} ohms) is sufficiently high to insure that the current drawn for the measurement is several orders of magnitude lower than the natural charging current, even at the maximum voltage readable in the instrument.

When the discharger was turned OFF, the voltage on the helicopter started to rise quite slowly. The time in which the voltage reached an apparently stationary reading was also recorded. It should be noted that this reading is given only as an estimate, as no specific instrumentation was prepared for this purpose. In addition, some of the measurements were found to be in excess of 50 kilovolts which was the limit of the available voltmeter. For these cases, the final voltage is recorded as "over 50 kilovolts". In one instance, the 10-kilovolt scale was used in order to get a better accuracy on the voltage reading with the discharger ON. In this particular case, the helicopter voltage with the discharger OFF is written as "over 10 kilovolts", for a similar reason.

The following sequence of measurements was followed for each test flight:

a. Take off with discharger OFF.
b. Drop ground line.
c. Read the natural charging current.
d. Let the helicopter voltage rise until it reaches a steady value. Record this value.
e. Turn the discharger ON. Read the helicopter voltage and the time required to reach this steady value.
f. Turn the discharger OFF. Let the voltage rise again. Read the final voltage and the time required to attain it.
g. Repeat (e.) and (f.).
h. Repeat (g.)
i. Recover the drop line and land the aircraft.

The above procedure gives three consecutive measurements of the helicopter voltage with the discharger ON and OFF for each test flight.

The natural charging current was also measured before each voltage reading. This measurement was made by grounding the helicopter through the hanging wire and using a series-connected microammeter.

The measurement of the discharger performance under artificial charge was made using the technique described in Figure 11.

The artificial charging tests were performed to check the operation of the dynamic neutralizer for negative charging conditions. It should be noted, however, that the test results should be considered only from a qualitative viewpoint. The reason for this is that true simulation of natural charging would require a generator having infinite voltage, infinite internal impedance, and charging the helicopter at a constant rate.

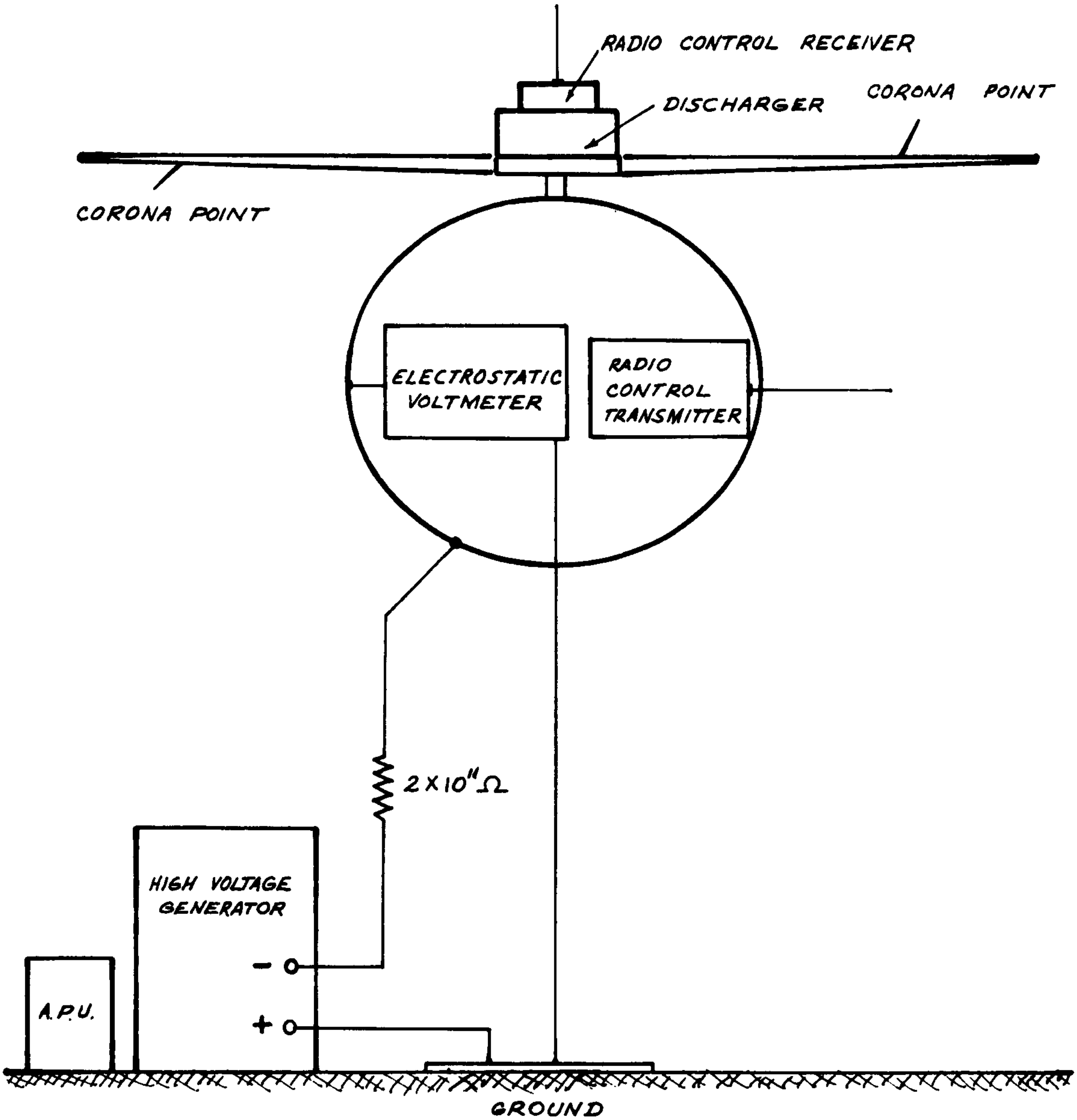


FIGURE 11: ARTIFICIAL CHARGING TEST SET-UP

VI. EXPERIMENTAL RESULTS

A. PARAMETRIC DATA ACQUISITION PHASE

The results of the parametric test program are presented in Figures 12 to 15. Figure 12 shows the effect of the air speed on the corona point current. The measurements were made with the truck grounded, and with a 20-kilovolt corona point potential.

Figures 13, 14 and 15 represent the performance of a corona point under varying corona point potentials with respect to the vehicles. Each curve is plotted for a constant vehicle-to-ground potential.

The corona points used in the tests of Figures 13, 14 and 15 are shown in Figure 16. Installation of these corona points are visible and encircled in Figure 8. The curves in Figures 13 and 14 correspond to a wire length of 20 inches, while the curves in Figure 15 were taken by using a wire length of 40 inches. The point consisted of a stripped polyethylene insulated steel cable, formed by 7 x 19 wires as shown in Figure 16.

Figure 17 shows other corona point configurations tested in this program. Table 1 gives the current obtained under similar conditions. The configuration in Figure 17 (configuration A on Figure 17) was considered to be a good compromise between good performance and design simplicity.

The parametric test phase was performed to obtain sufficient data for the design of the discharging devices which were to be tested in the flight test phase of the program.

As a consequence of the data in Figure 12 (the Effect of Air speed on Corona Point Performance), it was decided to install the discharging system in the rotor blades of the helicopter at a 20-foot-radius station. This location represents a compromise between high air speed and an acceptable level of centrifugal acceleration.

The presence of this centrifugal acceleration in the rotor blade installation was also considered when selecting the corona point length for the helicopter installation. From a mechanical standpoint, a short corona point is desirable.

NOTE: The corona point current shown in this figure is the discharging effect of the corona point. The readings were taken from the microammeter, $\mu A2$, Figure 9, while short-circuiting the terminals of the HVG-2 generator, which was inoperative.

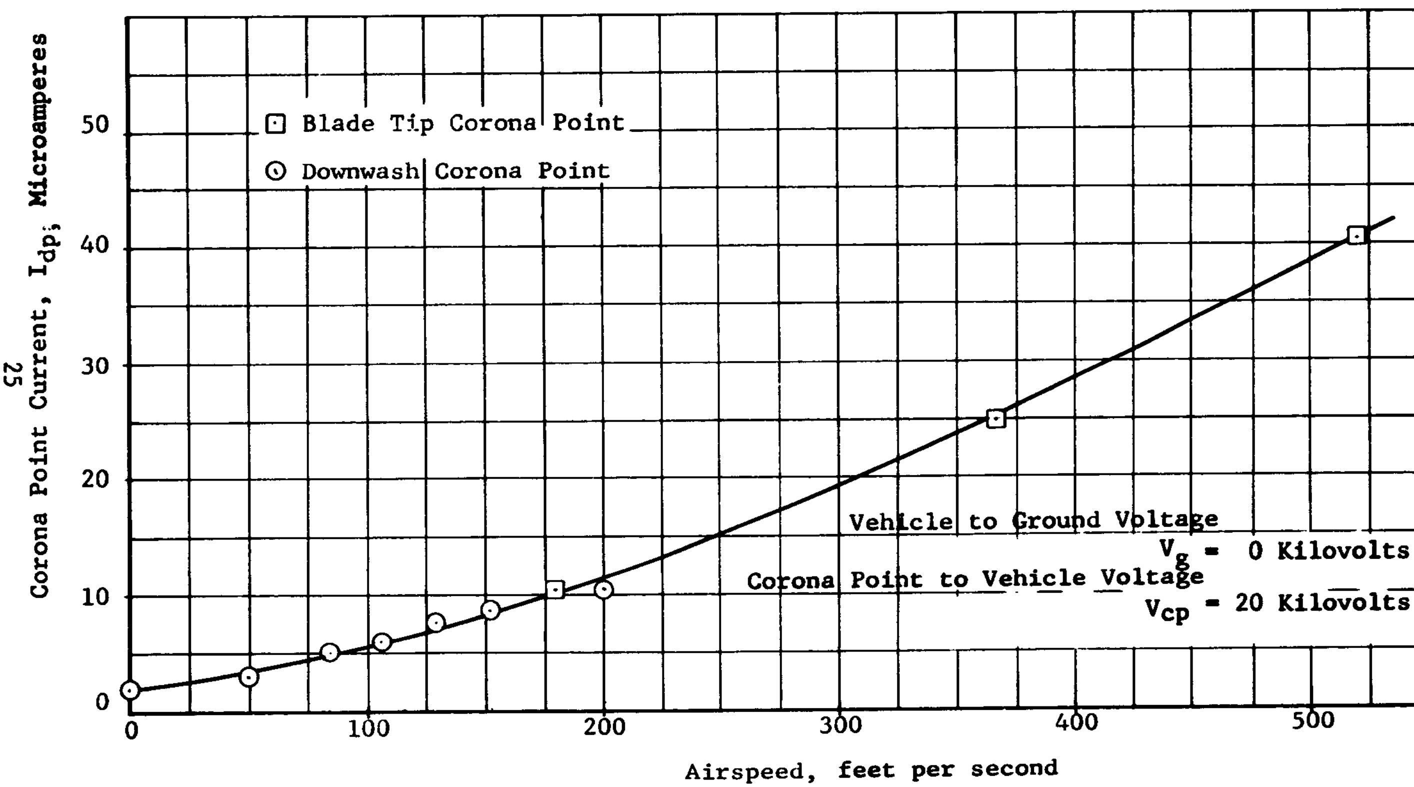


FIGURE 12 THE EFFECT OF AIRSPEED ON CORONA POINT PERFORMANCE

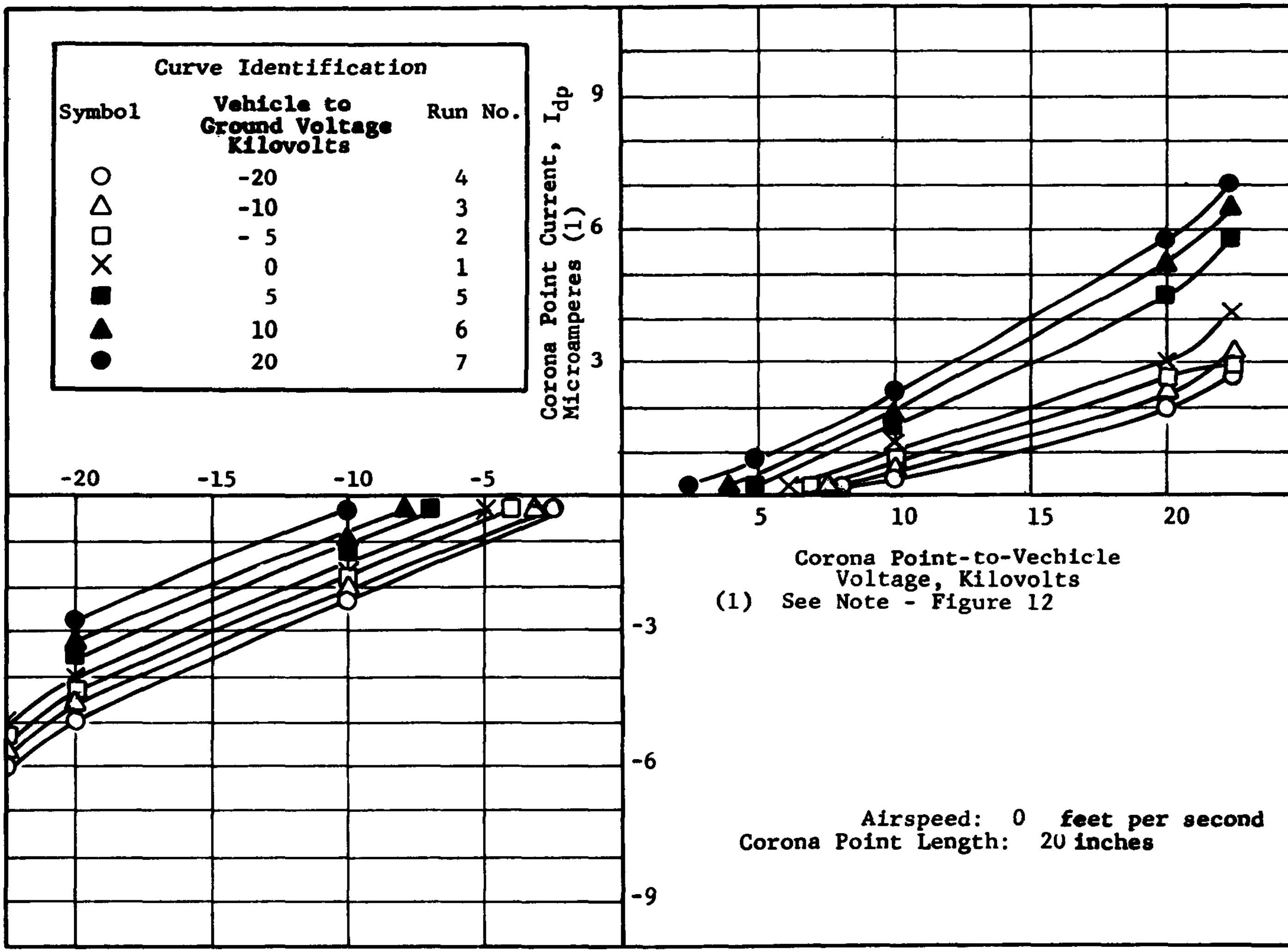


FIGURE 13: CORONA POINT PERFORMANCE CHART

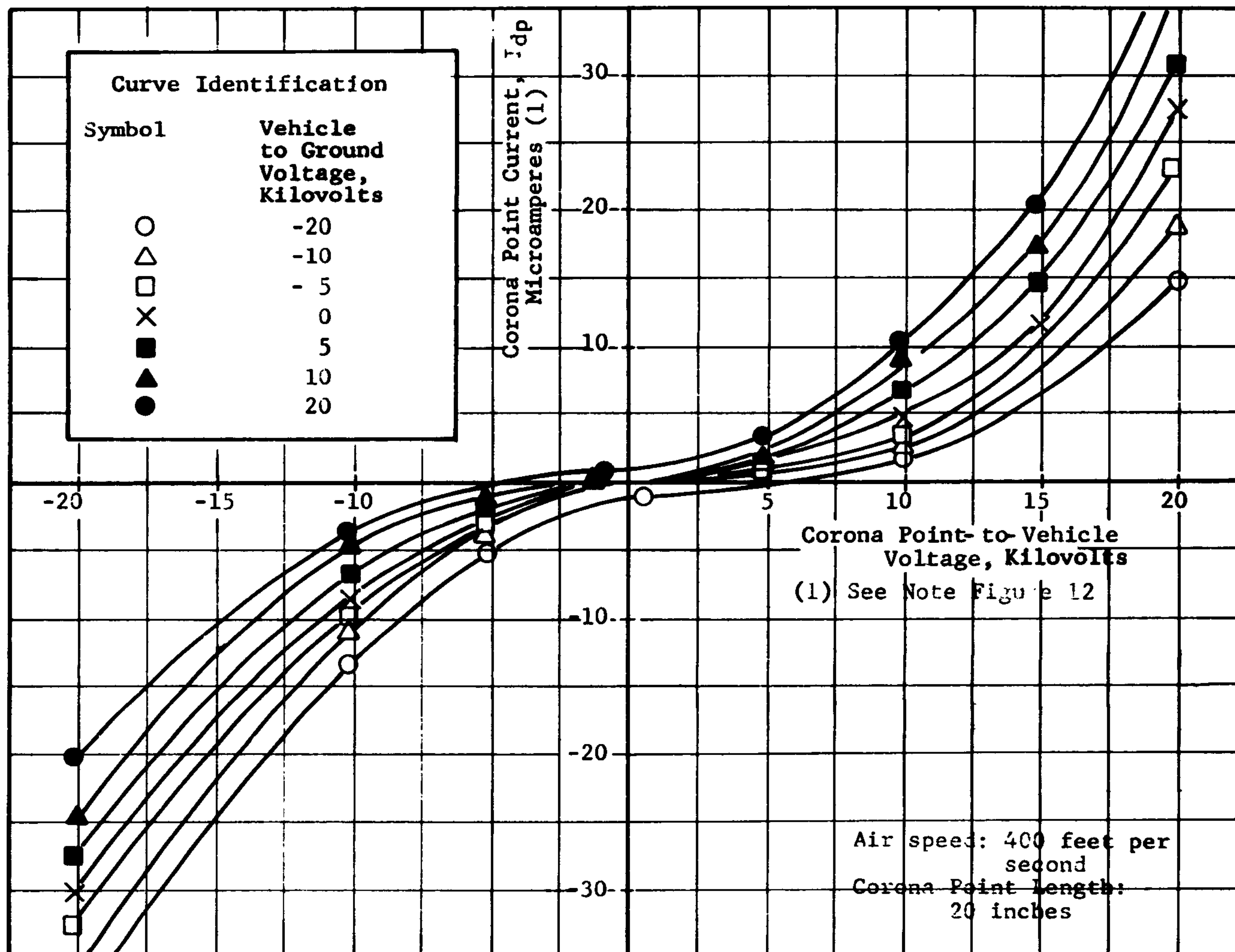


FIGURE 14: CORONA POINT PERFORMANCE CHART

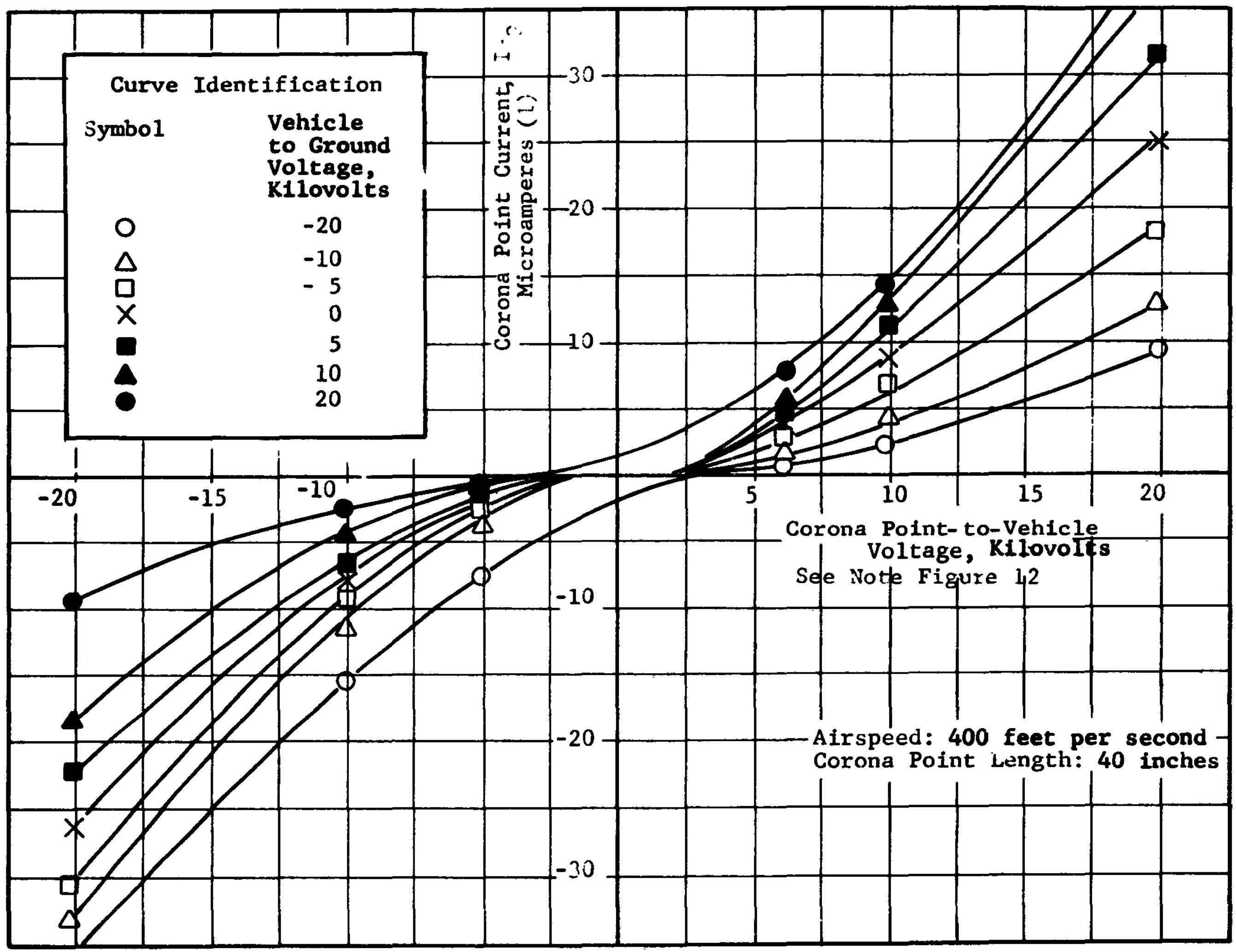


FIGURE 15: CORONA POINT PERFORMANCE CHART

FIGURE 16: CORONA POINT, TEST RIG

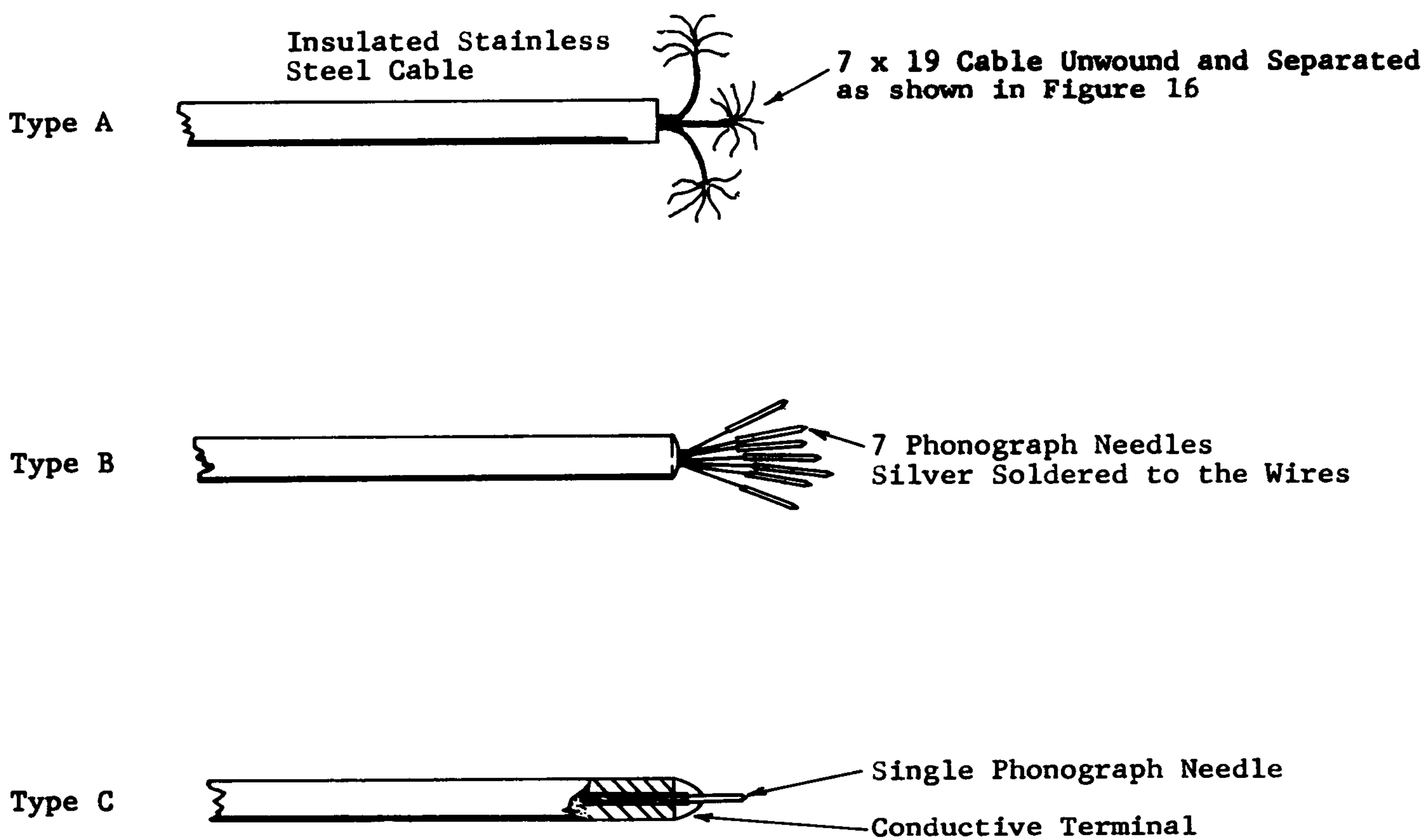


FIGURE 17: CORONA POINT CONFIGURATIONS

TABLE 1

EFFECT OF THE CORONA POINT GEOMETRY

ON THE CURRENT OUTPUT

Configuration (Ref. Fig. 17)	Current Microamperes
A	28
B	30
C	24

All tests performed with vehicle grounded and a corona point voltage of +20 kilovolts.

However, the comparison between the data on Figures 14 and 15 shows that a longer corona point will increase the sensitivity of the dynamic neutralizer principle of operations. An example is given here to illustrate how this conclusion was obtained from Figures 14 and 15.

The discharging action of the dynamic neutralizer is performed by the effect of the aircraft voltage on the output currents of corona points having the same potential with respect to the aircraft, but with opposite polarity. Assuming that this potential is 20 kilovolts, the operation of the corona points must be found along with +20 and -20 kilovolt vertical lines of both Figures 14 and 15. It can be seen that, for a neutral aircraft (0 kilovolt curves on both figures), the current output is 27.5 microamperes for both points in Figure 14 and 25 microamperes for both points in Figure 15.

Let it be assumed now that a natural charging current begins to charge the helicopter with a positive polarity, and that the magnitude of this current is 5 microamperes. A balanced condition will be obtained when the difference between the outputs of the positive and the negative points reaches 5 microamperes. Thus, in Figure 14, the positive output must rise from 27.5 to 30, while the negative output must decrease from 27.5 to 25. It is seen from Figure 14 that this change implies a vehicle voltage of about 4 kilovolts. However, in Figure 15, the neutralization of the assumed 5 microamperes charging current will require a positive output rise from 25 to 27.5 microamperes, together with a negative output current reduction from 25 to 22.5 microamperes. This condition is obtained with a vehicle voltage of approximately 2.2 kilovolts. Hence, a discharger based on the configuration of Figure 15 (40" corona point length) will perform better than one based on the configuration of Figure 14 (20" corona point length).

The slightly larger value of the corona point current at zero vehicle voltage, which is shown in Figure 14 (27.5 μA), with respect to the value shown in Figure 15 (25 μA), is believed to be due to air speed variations caused by errors in the propeller RPM adjustments during the testing. The effect that this small difference may have had in improving the performance of the Figure 14 configuration case, was overcome by the effect of the increase of corona point length corresponding to the data on Figure 15.

The results of the parametric testing agrees well with the predictions based on theoretical considerations.

Theoretically, if a corona point is located very close to the aircraft skin, the field between the point and the skin will be so high that the field due to the aircraft potential will have negligible effects on the corona point output. In other words, the motion of the ions will be under the almost exclusive control of the strong field created by the corona point voltage with respect to the vehicle skin. The effect of the relatively weak aircraft field will have little consequence on the resultant discharging action. For these conditions, no dynamic neutralizer action can be performed. On the contrary, an infinitely far separated corona point will have an output proportional to its voltage with respect to the surrounding atmosphere, and this voltage will be the algebraic addition of the aircraft voltage with respect to the atmosphere and the generator voltage with respect to the aircraft. In this case, the field created by the corona point voltage with respect to the vehicle skin will be weakened in points remote from the sharp corona points. Hence, the field created by the aircraft potential will be a significant factor in controlling the ion trajectories.

From the results of the parametric testing and the preceding discussion, it may be concluded that the dynamic neutralizer performance may be improved in two ways:

1. By increasing the length of the corona point.
2. By locating the corona points in a zone as flat as possible in the helicopter fuselage in order to reduce the aircraft generated field at the chosen corona point distance.

B. DISCHARGER UNIT FLIGHT TEST

Tables 2, 3, 4 and Figure 18 give the results obtained by flight test of the device. The test was performed at Edwards Air Force Base, California, between 23 September and 8 October 1961. Figure 19 shows the H-37 helicopter used in the test program; Figure 20 shows the H-37 helicopter corona point. All testing was done with the helicopter hovering at an altitude between 15 and 25 feet in fair weather. All natural charge was found to be of positive polarity.

1. PCPSD Principle Test Results

The testing of the PCPSD version of the discharger was performed over concrete covered ground using the circuit shown in the drawing 195-SK-802-15, Appendix I. In this circuit, the current flowing through the passive corona point sensor is fed into the input of a differential DC preamplifier powered by a floating 6-volt DC battery.

TABLE 2

ARTIFICIAL CHARGING

TEST RESULTS

DYNAMIC NEUTRALIZER PRINCIPLE

Natural Charging Current (measured before the artificial charger was connected)	1.8	A (positive)
High-Voltage Generator Output	-30	KV
Helicopter Voltage, Discharger OFF	-29	KV
Helicopter Voltage, Discharger ON	- 1.5	KV
Time to Charge to Maximum Value	20	Sec.
Time to Discharge to Minimum Value	9	Sec.

TABLE 3

ELECTROSTATIC DISCHARGER PERFORMANCE

DYNAMIC NEUTRALIZER PRINCIPLE

NATURAL CHARGING CONDITIONS

Flight number	1	2	3
Surface type	Concrete	Water	Asphalt
Natural charging current, microamperes	1.6	1.8	1.5
Generator voltages before the flight:			
Positive output, kilovolts	20	20	20
Negative output, kilovolts	20	20	20
Helicopter voltage, discharger OFF, kilovolts	>50	>50	>50
Time to charge, seconds	15	-	20
Helicopter voltage, discharger ON, kilovolts	1.7	0.7	1.0
Time to discharge, seconds	2	2	2
Helicopter voltage, discharger OFF, kilovolts	>50	>50	>50
Time to charge, seconds	13	18	15
Helicopter voltage, discharger ON, kilovolts	1.8	0.7	0.9
Time to discharge, seconds	2	2	2
Helicopter voltage, discharger OFF, kilovolts	>50	>50	>50
Time to charge, seconds	12	17	16
Helicopter voltage, discharger ON, kilovolts	1.95	0.7	1.2

TABLE 3 (CONTINUED)

Flight number	1	2	3
Surface type	Concrete	Water	Asphalt
Time to discharge, seconds	2	2	2
Generator voltages after the flight:			
Positive output, kilovolts	17.5	20	20
Negative output, kilovolts	18	20	19.5

TABLE 4

ELECTROSTATIC DISCHARGER PERFORMANCE

PCPSD PRINCIPLE

NATURAL CHARGING CONDITIONS

Flight number	1	2	3
Surface type	Concrete	Concrete	Concrete
Natural charging current, microamperes	+2	+2	+2.2
Helicopter voltage, discharger OFF, kilovolts	>50	>50	>50
Time to charge, seconds	20	22	20
Helicopter voltage, discharger ON, kilovolts	5-5.5	5	5-5.5
Time to discharge, seconds	10	11	12
Helicopter voltage, discharger OFF, kilovolts	>50	>50	>50
Time to charge, seconds	16	16	15
Helicopter voltage, discharger ON, kilovolts	5	5	5.5
Time to discharge, seconds	11	11	11
Helicopter voltage, discharger OFF, kilovolts	>50	>50	>50
Time to charge, seconds	25	20	22
Helicopter voltage, discharger ON, kilovolts	5	5.5	5.5

NOTE: This test was repeated with the differential amplifier unbalanced in the positive direction. The results obtained were basically the same as those reported above.

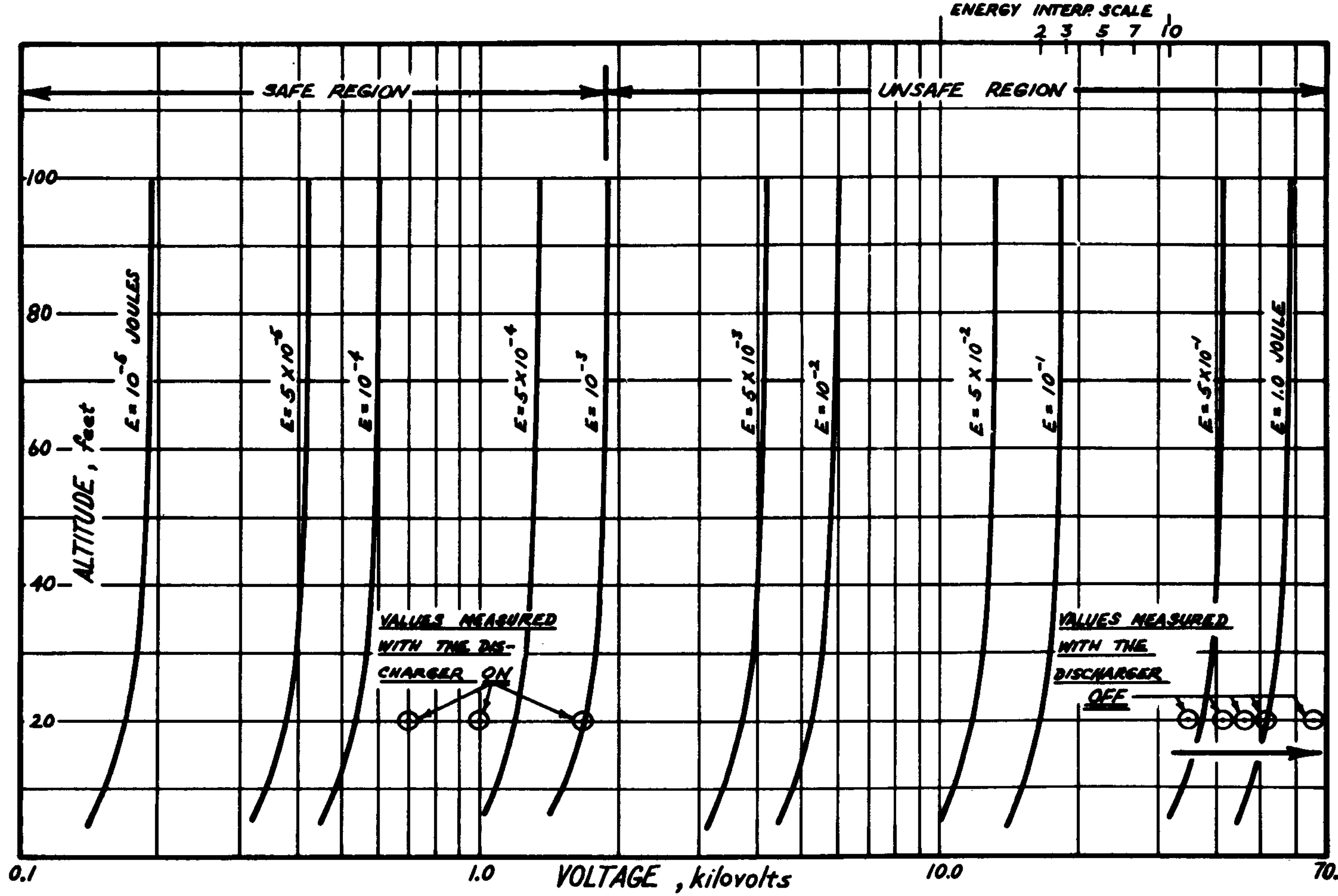


FIGURE 18: DISCHARGER OPERATION GRAPHICAL PRESENTATION

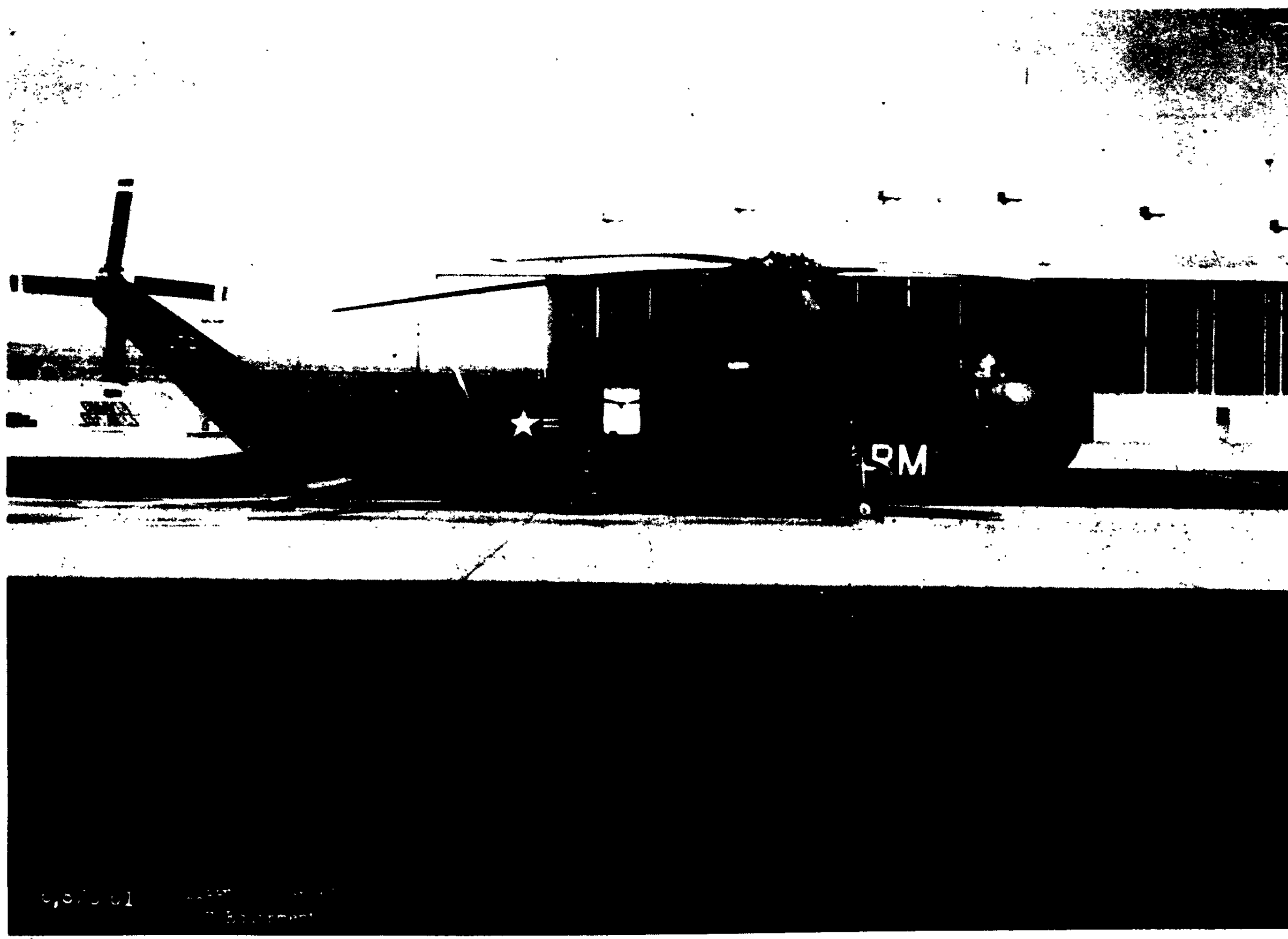


FIGURE 19: H-37 AIRCRAFT USED IN THE DISCHARGER FLIGHT TESTING

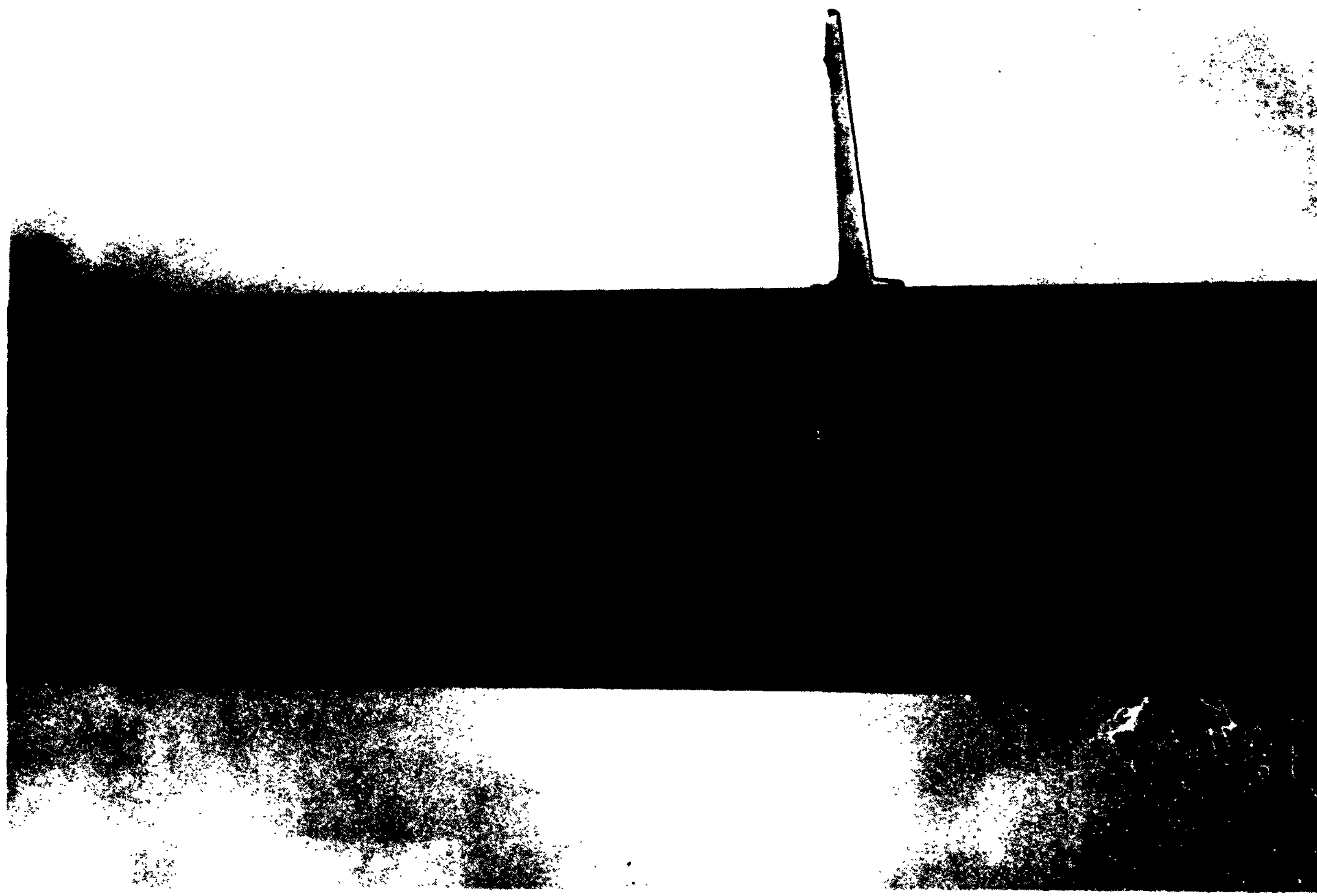


FIGURE 20: H-37 CORONA POINT

At the output of the preamplifier, a polarity-sensing resistor-diode network feeds the output of the differential preamplifier to two DC control amplifiers which, in turn, control the amount of feedback present in two standard saturated-transformer-type power oscillators.

The secondary coils of the oscillator transformers are fed into two high-voltage rectifying-doubling circuits, wired with opposite polarities.

The overall performance of the system was such that both high-voltage outputs were OFF with currents below ± 0.5 microampere on the input circuit, while currents over ± 0.5 microampere determined the operation of either the positive or the negative high-voltage generator, depending on the respective polarity of the input current. Noise and drift considerations limited the sensitivity of the control amplifiers to these values. Figure 21 is a plot of the performance of the device as obtained during bench testing. Capacitors C_5 and C_6, Reference Appendix I, were used to provide a reaction time of the unit in the order of 0.1 second, thus filtering out the high frequency components of the corona discharge flowing through the passive corona point and contributing to eliminate any possible AC feedback between the high power stages of the unit and its input circuits, which could otherwise lead to unwanted oscillations. Resistors R_{10} and R_{11}, Reference Appendix I, provided some reverse polarity bias to the input circuits of each control amplifier when the other polarity circuit was in operation. In this manner, the possibility of simultaneous operation of both generators in the DC amplifiers was avoided.

The OFF-ON switching of the discharger was performed by a radio-operated relay, to avoid the necessity of using a slip-ring and brush type device.

The relay switched all batteries ON or OFF under the command of the radio transmitter, which was installed on the rear fuselage window of the aircraft.

The performance of the PCPSD principle was investigated in the first part of the flight test program. The results are included in Table 4. The helicopter voltage with the unit in operation came down to 5 kilovolts, in a very consistent manner. The same test was repeated three times in each one of three different flights, with similar results.

An attempt was made to decrease the helicopter final voltage by unbalancing the differential amplifier down to a point very close to the point of ON switching of the positive high-voltage generator. This was done in order to obtain

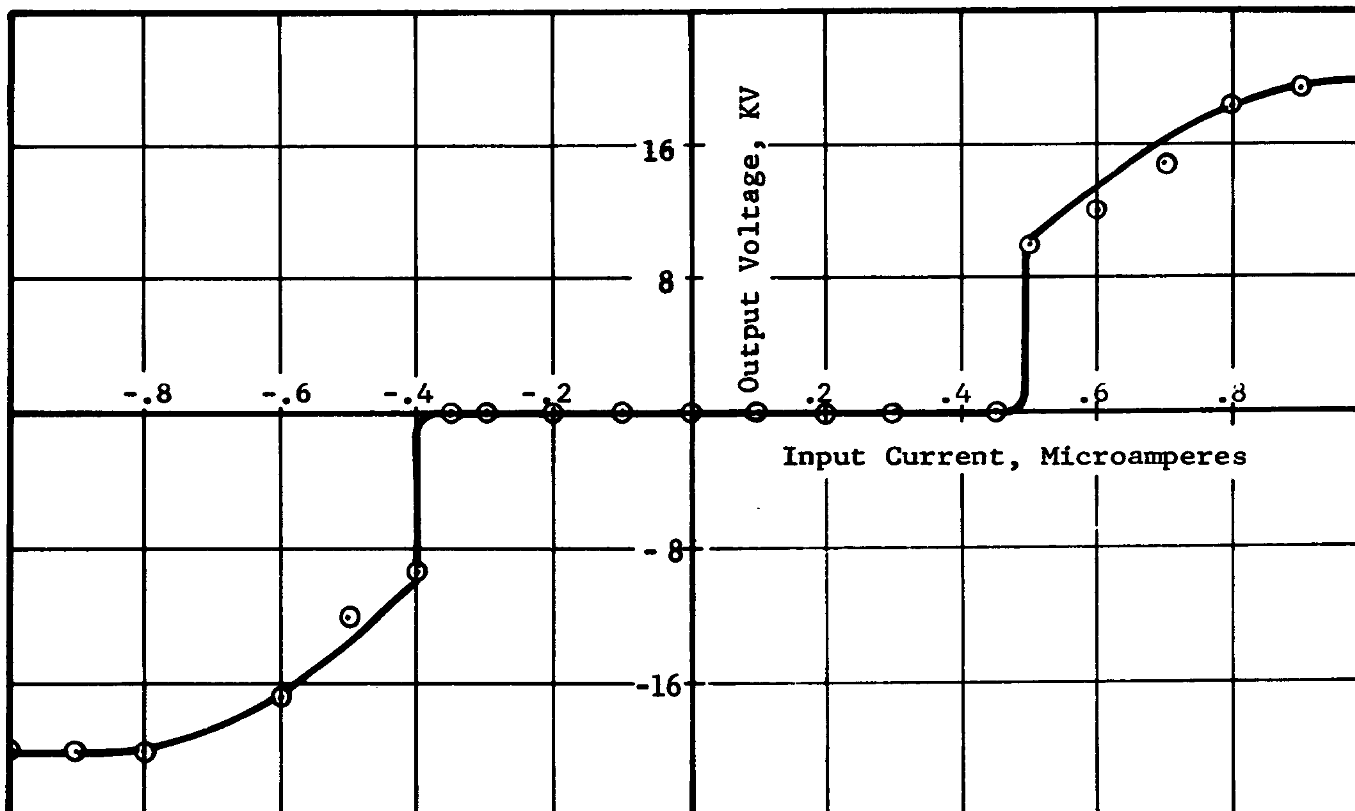


FIGURE: 21 PCPSD DISCHARGER BENCH-TEST PERFORMANCE results equivalent to those which could be obtained with a more sensitive amplifier. The natural charge at the test site was always positive. Hence, the decreased sensitivity of the negative channel was not considered objectionable for this test location.

2. Dynamic Neutralizer Principle Test Results

The testing of the dynamic neutralizer principle of operation was performed by using the circuit shown in Figure 1. Actually, this configuration was obtained by merely short-circuiting the collector to the emitter of both 2N386 control transistors, and disconnecting the battery powering the differential preamplifier used in the testing of the PCPSD principle. In this manner, as soon as the power relay was switched ON by the radio-control system, both the positive and the negative high-voltage generators became operative. The output voltage of the generators is a function only of the feedback resistor and the battery voltage of the respective generator.

The batteries used in this unit were rated at 1.25 amperes-hour, and the load of each one of the batteries powering the high-voltage generators was of the order of 1 ampere, depending on the value of the feedback potentiometer. The batteries were of the nickel-cadmium rechargeable type, and were chosen because it represented a compromise between minimum weight and reasonable cost. However, the output voltage of the batteries was not uniform during the entire discharging operation.

The operation of the dynamic neutralizer principle depends on the presence of two DC voltages of the same magnitude but opposite polarity. It has been mentioned previously that the output voltage of the generator was affected by the battery voltage, and the latter was a function of the status of charge and the rate of discharge of the battery. So, in order to maintain the outputs of both generators at equal levels, operations were performed with both batteries charged as high as possible. The batteries were replaced by fully charged batteries every fifteen minutes of operation.

In order to ascertain that the voltage of both positive and negative generators was identical throughout the test, these voltages were measured before and after each test flight. The time elapsed between both voltage checks was of the order of 30 minutes. On several occasions, the output voltage of one generator after the test flight was found to be somewhat different from the output voltage of the other generator. The magnitude of the unbalance is presented in Table 3, together with the results of this testing. It can be observed in Table 2 that the helicopter voltage with the dynamic neutralizer ON was higher in each consecutive reading of the same flight, except in the testing over water. It may also be observed that in over-water tests (Flight no.2) the balance on the neutralizer was maintained throughout the test. This was attained by reducing the time duration of the periods with the generator ON in order to conserve battery power.

As shown in Table 3, the output voltage of the positive generator was lower than the output voltage of the negative generator at the end of Flights 1 and 3 over concrete and asphalt respectively. The effect of a positive corona point with less voltage than its negative counterpart is a reduced current output on the positive corona point. Hence, under such unbalanced conditions and with positive natural charge present, it is obvious that a larger helicopter voltage will be required in order to reach equilibrium.

It must be emphasized that the problem of balance of the dynamic neutralizer can be solved by suitable design, embodying the use of a single battery and, preferably, of a single high-voltage transformer powering two high-voltage rectifiers. In the present program, however, the dynamic neutralizer principle was tested utilizing the discharger built for the tests of the PCPSD principle. It should be realized that, although the modified unit may be considered as adequate for test purposes, an actual dynamic neutralizer would require some redesign of the equipment used for this program. Figure 1 presents a preliminary schematic diagram of the design of a dynamic neutralizer discharger.

The performance of the dynamic neutralizer was measured with the helicopter hovering over three different types of terrain: concrete, asphalt, and water.

3. <u>Artificial Charging Tests</u>

Table 2 presents the data obtained during the artificial charging tests. As observed in this table, the discharger operates satisfactorily under negative charging conditions. However, no quantitative conclusions can be obtained from these data, inasmuch as these tests do not represent a true simulation of natural charging. The natural charging current is independent of helicopter voltage, whereas the artificial test setup resulted in different charging rates for different aircraft voltages. True simulation can be obtained, therefore, only with a constant current generator having infinite internal impedance and infinite voltage.

C. COMPARISON BETWEEN THE PCPSD AND THE DYNAMIC NEUTRALIZER PRINCIPLES

The data presented in this report can be used to compare the performance of the two principles of discharging used in the program.

It has been shown that the dynamic neutralizer principle reduces the helicopter voltage to a level lower than the level attained when using the PCPSD principle. However, it is noted that the final voltage of the helicopter with the dynamic neutralizer is a function of the natural charging current generated by the aircraft. This dependence is not proved by the flight test data because the natural charging current at the test site remained practically constant during the test period. This dependence has been deduced from the parametric testing as explained earlier in this report.

On the contrary, the final voltage of a helicopter equipped with a discharger using the PCPSD principle is only a function of the sensitivity of the passive corona point sensor. This implies the assumption that the natural charging current does not exceed the output current of the active corona point of the corresponding polarity. It appears that the sensing device tested in the helicopter installation did not carry .5 A at helicopter voltages lower than 5 kilovolts. At this value, the helicopter energy exceeds the 1 millijoule level established as satisfactory.

Consequently, it may be concluded that the dynamic neutralizer principle is a better solution to the problem of discharging a helicopter. This conclusion is valid only if the voltage remaining in the helicopter with the dynamic neutralizer in operation, can be maintained at a satisfactory level. The utility of the dynamic neutralizer, however, is expected to decrease if larger natural charging currents are encountered.

In comparing the results of both principles of operation, it is noted that the discharging time recorded with the dynamic neutralizer principle is substantially lower than the discharging time read with the PCPSD system. This result is unexpected, because the output of the single corona point of the PCPSD system is larger than the differential effect of the dynamic neutralizer, and this should produce a faster discharge with the former principle. No conclusive explanation has been found for this discharging behavior. It is believed, however, that an intermittent ON-OFF action of the PCPSD device could have produced the apparent slow discharge rate, which might have been produced by a damped parasitic oscillation of the system during its operation far from the equilibrium condition.

D. MISCELLANEOUS TEST RESULTS

Other information obtained during the flight test program is presented.

1. Radio Interference

No specific radio interference measurements were made during the tests. However, the aircraft was operated at all times with two radio receivers ON. These receivers operated at 264.9 megacycles per second and 540 kilocycles per second. No interference was noticed as a result of the operation of either of the devices tested in the program.

2. Aircraft Flight Characteristics

No specific measurements were made on the effect of the installation on the rotor blades of the corona point and associated wiring. However, the test pilot was requested to report his opinion on this matter. The pilot's opinion is as follows:

a. A qualitative evaluation of the flying characteristics of H-37A, serial number 55-621, was made with the modified narrow chord, main rotor blades installed. These blades were modified by Kellett for the Static Electricity tests conducted at the Army Test Office, Edwards, AFB, California.

b. Flights were conducted under varying conditions of hovering (10-100 feet) and forward flight up to 80 knots to altitudes of 7000 feet. There was no difficulty in maintaining the main rotor blades in desired track, and under all flight conditions no unusual vibrations were noted.

c. Operation with the modified main rotor blades installed on the H-37 was completely satisfactory, and no difference could be noted from using the modified blades over standard production items.

3. Blade Wiring Insulation Test

After the completion of the flight test program, a test was carried out to determine the maximum insulation capability of the blade installation and the maximum output of the high-voltage generator. The positive generator was connected to one blade and its voltage was raised until a failure was experienced.

The wire installation in the blades with serial numbers, 56M-1462, 56M-1478 and 56M-1352 failed at voltages of about 42 kilovolts. Failure is defined here as a loss of the insulation at voltages over a few kilovolts. This failure was of a permanent nature.

The blades were inspected again upon their arrival at the Contractor's plant after the completion of the test program. The three blades mentioned above were still short-circuited. The two remaining blades (serial numbers 56M-1420 and 56M-1470) were still preserving good insulation characteristics up to 20 kilovolts.

4. Human Sensitivity to Electrostatic Discharge

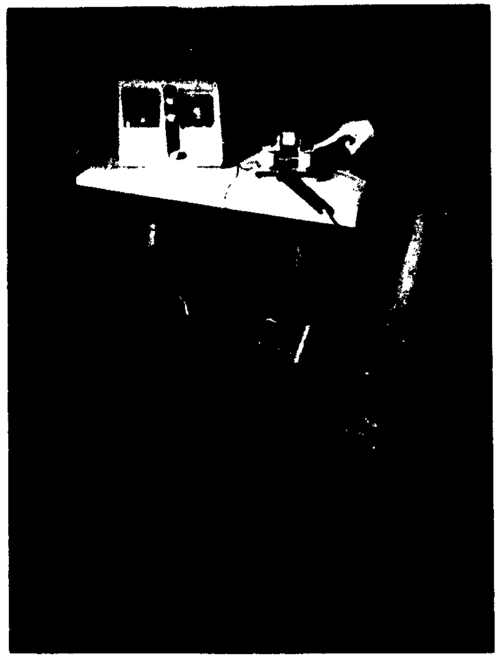
The sensitivity of humans to electrostatic discharge has been reported in References 3 to 6. From these references it may be concluded that a discharge involving an energy release of 1 millijoule may be considered as the minimum level detectable by an average person.

In order to verify this information, this Contractor has performed a survey using capacitance values in the same range as the capacitance of an H-37 Army helicopter.

The voltmeter used to read the voltage in the capacitor (Sweeny Model ETVM) has an input impedance of 10^{14} ohms. The capacitor used in the testing has a value of 750 microfarads equivalent to an H-37 hovering at 15 feet, as shown in Figure 2. The time constant of the capacitor-voltmeter combination was several hours. In fact, during the testing, no readable change on the voltmeter indication was observed after the disconnection of the voltage source from the capacitor.

The test was performed as shown in Figure 22 and is described as follows:

A high-voltage generator was connected to the capacitor-voltmeter combination. The output of the generator was 500 volts in the first trial, and was subsequently raised by 100-volt steps. Once the capacitor was charged, the generator was removed and the test operator touched the upper plate of the capacitor bank. A reading was made of the voltage at which the operator was able to feel the discharge. The test was conducted by using five different persons, and the results may be considered as identical for all of them. The test was conducted with the human test subject standing on four different types of surfaces. Table 5 gives the result of this survey. From the results of Table 5, it was concluded that the value of 1 millijoule represents a good value of the human threshold of sensitivity to electrostatic discharge.



TEST SET UP

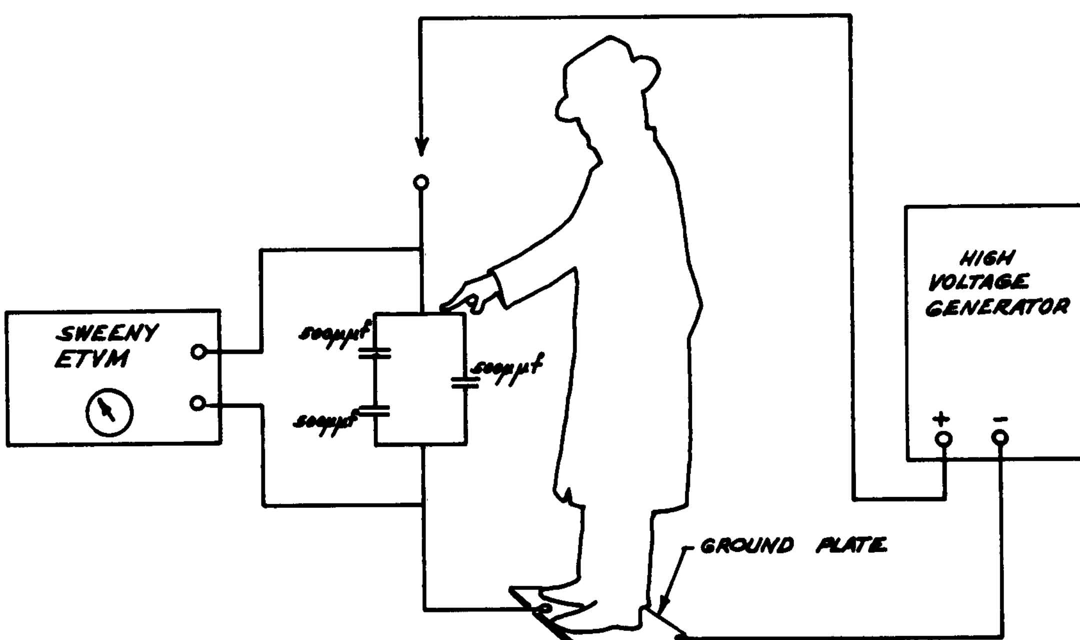


FIGURE 22: HUMAN THRESHOLD OF SENSITIVITY TO ELECTROSTATIC DISCHARGE, TEST SET UP

TABLE 5

THRESHOLD OF SENSITIVITY TO ELECTROSTATIC DISCHARGE

Capacitance: 750 microfarad

TYPE OF STANDING SURFACE	VOLTAGE	ENERGY
Grounded Metal Plate	1400 volts	.74 millijoules
Concrete	1800 volts	1.22 millijoules
Asphalt	1900 volts	1.36 millijoules
Damp Ground	1500 volts	.85 millijoules

VII. BIBLIOGRAPHY

1. Stimmel, R. G., Ronald, G., Rogers, E. H., Waterfall, F. E., and Gunn, R., Army-Navy Precipitation Static Project, Proc. Inst. Radio Eng., Vol. 34 Nos. 4 and 5, April and May 1946.

2. Hall, W. C., Electrostatic Dischargers for Aircraft, Journal of Applied Physics, Vol. 18, No. 8, August 1947, Pages 759-765.

3. Cierva, J. de la, Perlmutter, A. A., and Goland, L., Proposal for a Static Electricity Discharge Device for Helicopters, Kellett Aircraft Corporation Report No. 195X80-1, 7 November 1960.

4. Newman, M. M. and Robb, J. D., Investigation of Minimum Corona Type Currents for Spark Ignition of Aircraft Fuel Vapors, NASA TN D-440, June 1960.

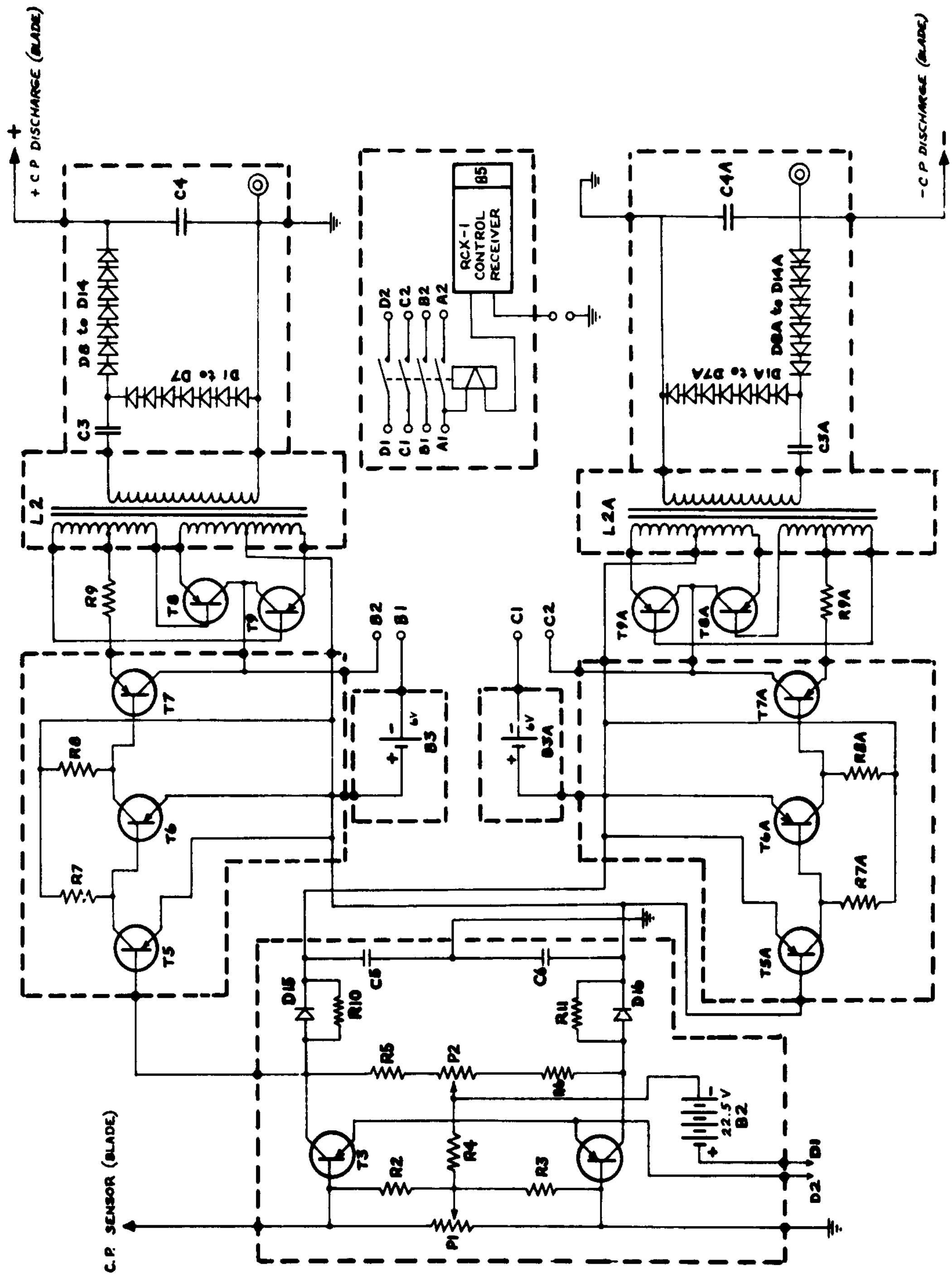
5. Bush, A. M., Electrostatic Spark Ignition-Source Hazard in Airplane Crashes, NACA TN 3026, October 1953.

6. Anon., Static Electricity, U. S. Air Force "Aerospace Accident and Maintenance Review", November 1960.

7. U. S. Navy Contract NOw 60-0450-f, VTOL, Downwash Design Criteria.

APPENDIX I

ELECTRICAL SCHEMATIC, H-37 STATIC DISCHARGER



Kellett Drawing Number 195SK802-15

APPENDIX II

INSTALLATION, H-37 STATIC ELECTRICITY DISCHARGER

A. WEIGHT STATEMENT, POUNDS

1. Static Discharger			
	a. Generator-amplifier package	10.540	
	b. Batteries	2.150	
	c. Remote switch, radio receiver	.110	
			12.800
2. Probes (5)			1.500
3. Wire (5 blades)			1.805
4. Miscellaneous hub and blade root fittings, bolts, etc. (5 blades)			12.275
		Total pounds	28.38

No attempt was made to minimize weight or to miniaturize; significant weight economies are possible for prototype and production equipment.

B. MATERIALS

1. Probes-fiberglas

Unidirectional fabric #143 was used with Armstrong C-7 layup adhesive.

2. Batteries

Everready #763, $22\frac{1}{2}$ volt, 1 required.
Everready #744, 6 volt, 3 required.

3. Wire

a. Blade Span

0.045 inch diameter, HFX-TWH 24-1/24 teflon insulated wire; Hytemp Wire Co., Westbury, N.Y.

b. Blade Root

3/32 inch galvanized steel core cable/polyethylene tape insulation; Boston Wire and Cable Co., Boston, Massachusetts

4. Bonding Agent - Wire to Blade: C-7 adhesive.

DISTRIBUTION

USCONARC	3
Seventh US Army	1
USAIC	2
USACGSC	1
USAWC	1
USAATBD	1
USAAVNBD	1
USATMC(FTZAT), ATO	1
ARO, Durham	2
OCRD, DA	1
NATC	2
ARO, OCRD	1
TO, USAAVNC	1
USAAVNS, CDO	1
CECDA	1
USATCDA	1
USATB	1
USATMC	21
USATEA	1
USATC&FE	4
USATSCH	3
USATRECOM	67
USA Tri-Ser Proj Off	1
TCLO, USAABELCTBD	1
USATRECOM LO, USARDG (EUR)	1
TCLO, USAAVNS	1
USARPAC	1
AFSC(SCS-3)	1
Air Univ Lib	1
AFSC (Aero Sys Div)	2
ASD (ASRMPT)	1
ONR	3
BUWEPS, DN	5
ACRD(OW), DN	1
USNPGSCH	1
CMC	1
MCLFDC	1
MCEC	1
MCLO, USATSCH	1
NAFEC	3
Langley Rsch Cen, NASA	2

Ames Rsch Cen, NASA	2
Lewis Rsch Cen, NASA	1
Sci & Tech Info Fac	1
ASTIA	10
USAMCAFO	1
USASRDL	2
Marine Acft Gp 36	1
SG	1
USAMOCOM	3
USSTRICOM	1
USAMC	4
Kellett Acft Corp.	10

AD_____ Accession No._______ Unclassified

Kellett Aircraft Corporation, Willow Grove, Pa., HELICOPTER STATIC ELECTRICITY DISCHARGING DEVICE - J. de la Cierva

TCREC Technical Report 62-33, December 1962, pp. (Contract DA 44-177-TC-728) USATRECOM Task 9R38-01-017-30 Unclassified Report

This report presents the results of a program for the alleviation of static electricity(Over) Unclassified

1. Air Cushion Vehicles
2. Contract DA 44-177-TC-728

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Kellett Aircraft Corporation, Willow Grove, Pa., HELICOPTER STATIC ELECTRICITY DISCHARGING DEVICE - J. de la Cierva

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Unclassified

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